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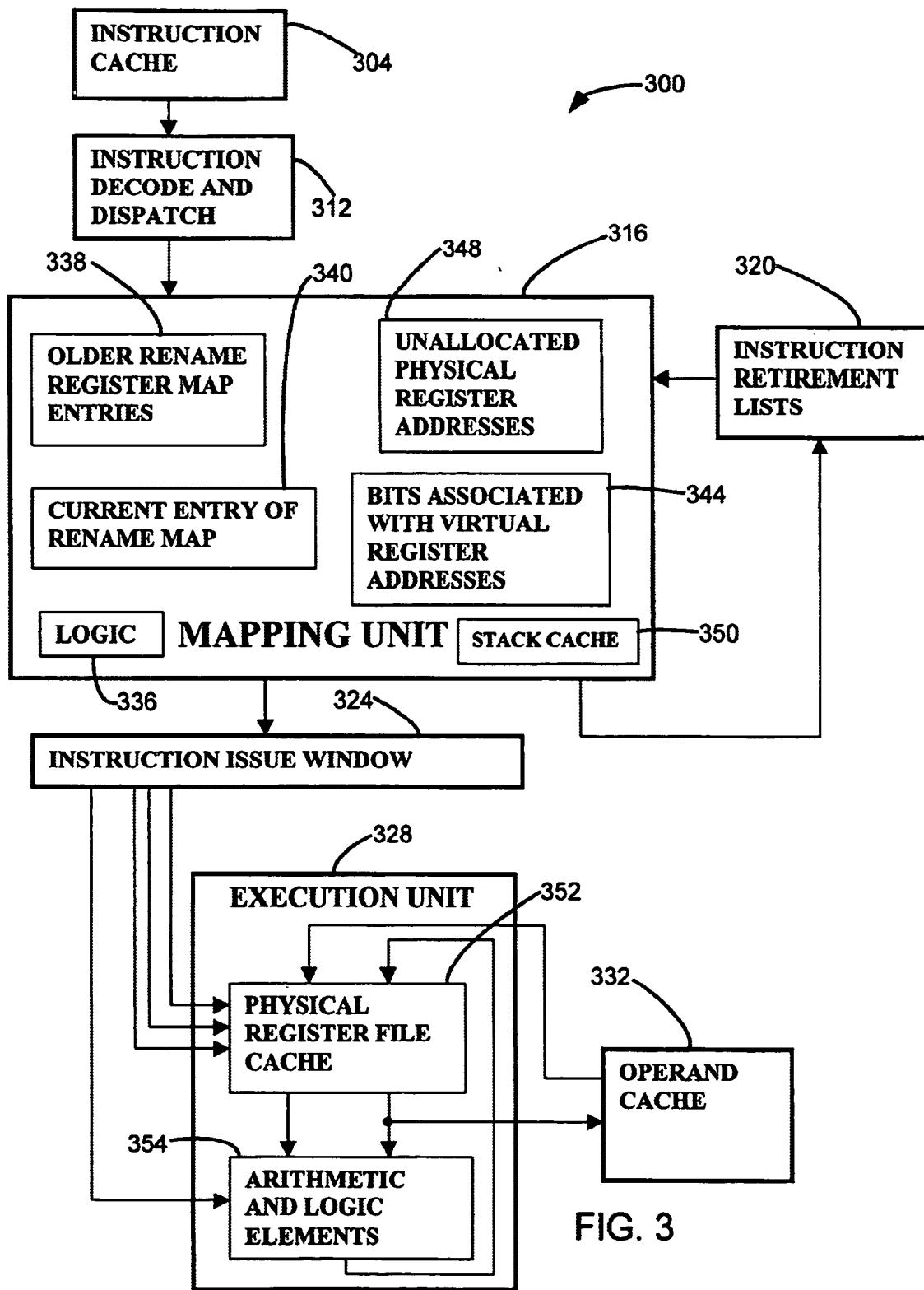


FIG. 3

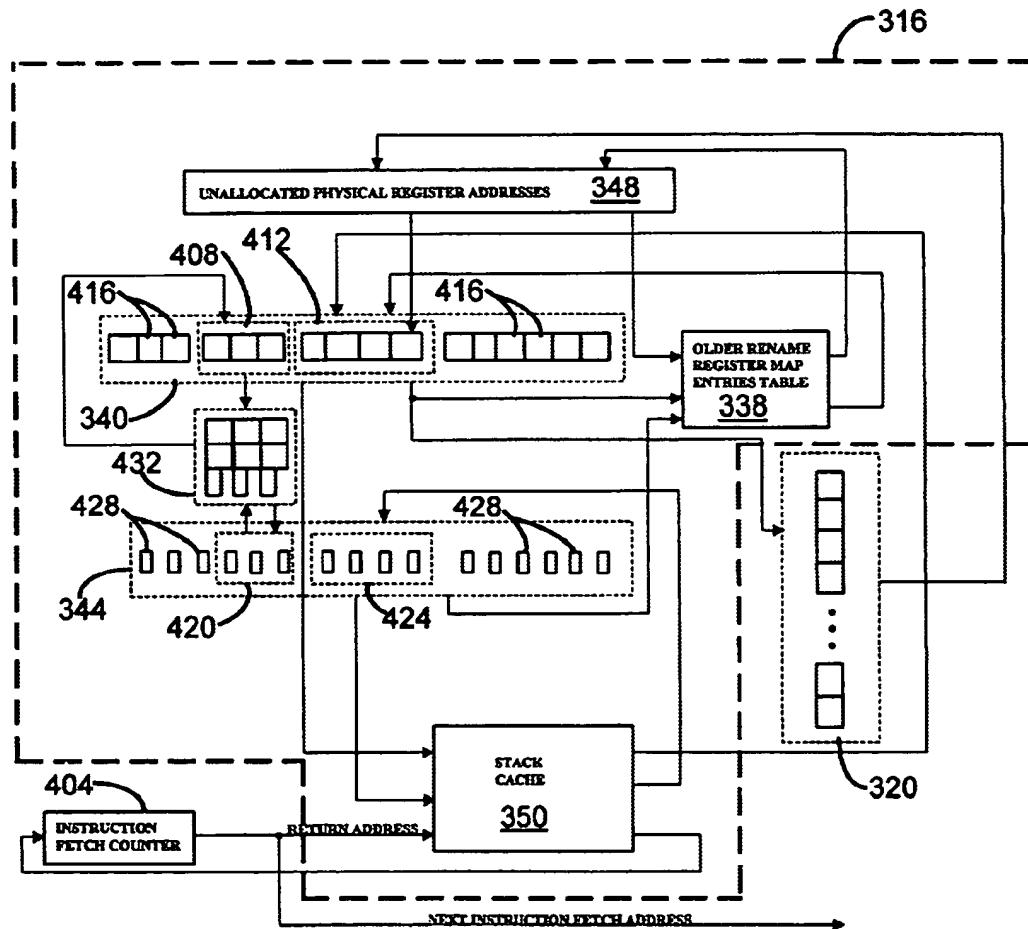


FIG. 4

00000000000000000000000000000000

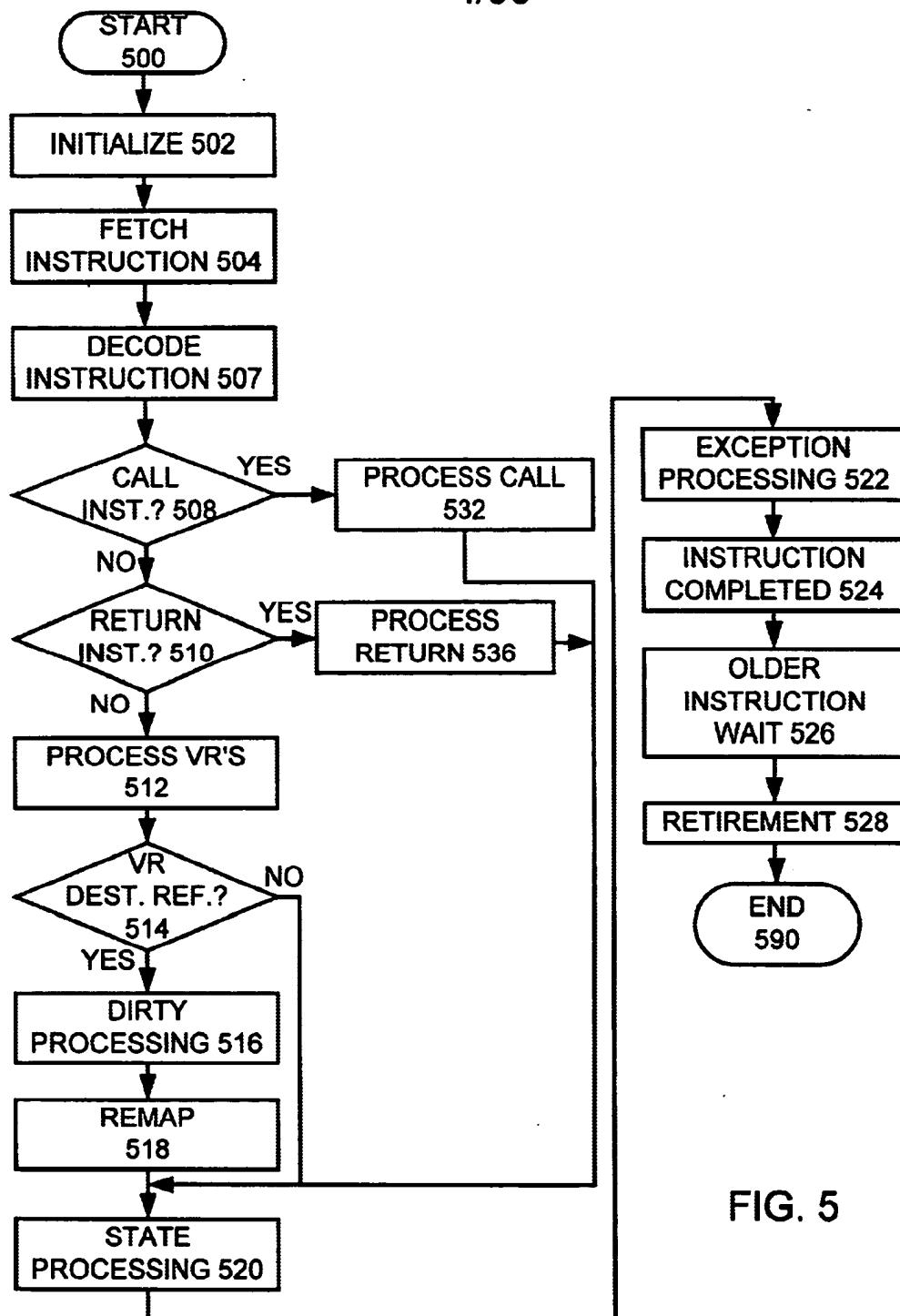
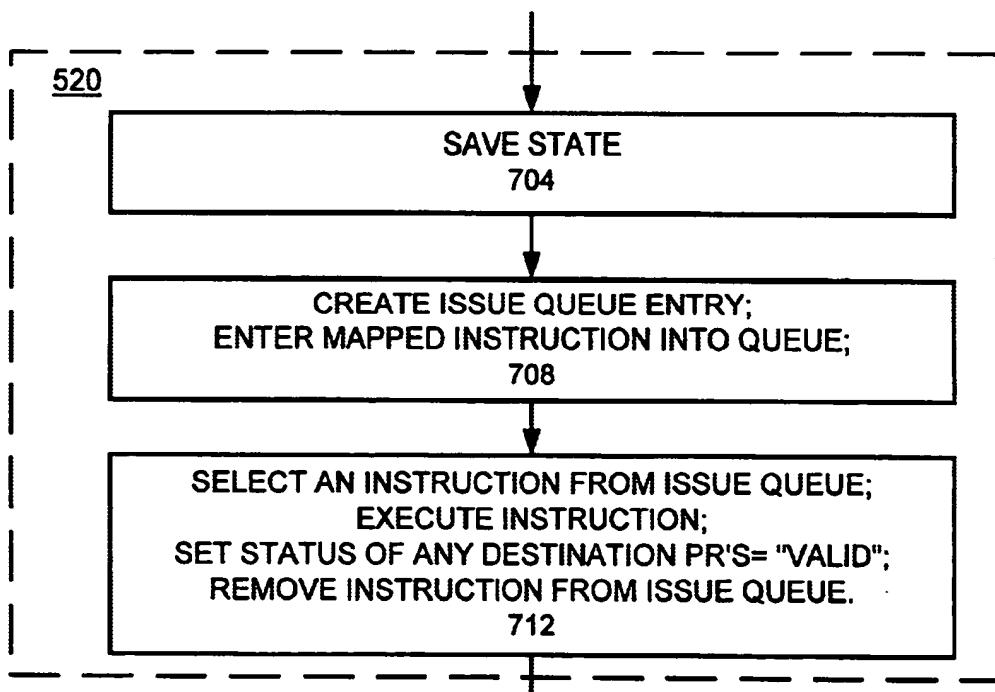
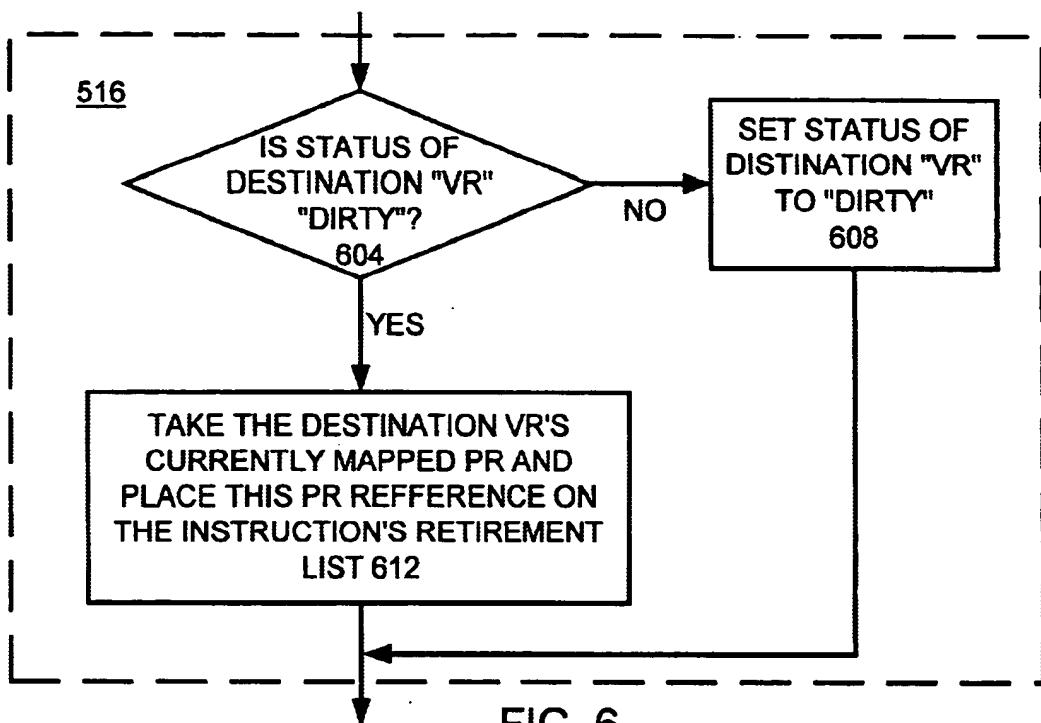


FIG. 5



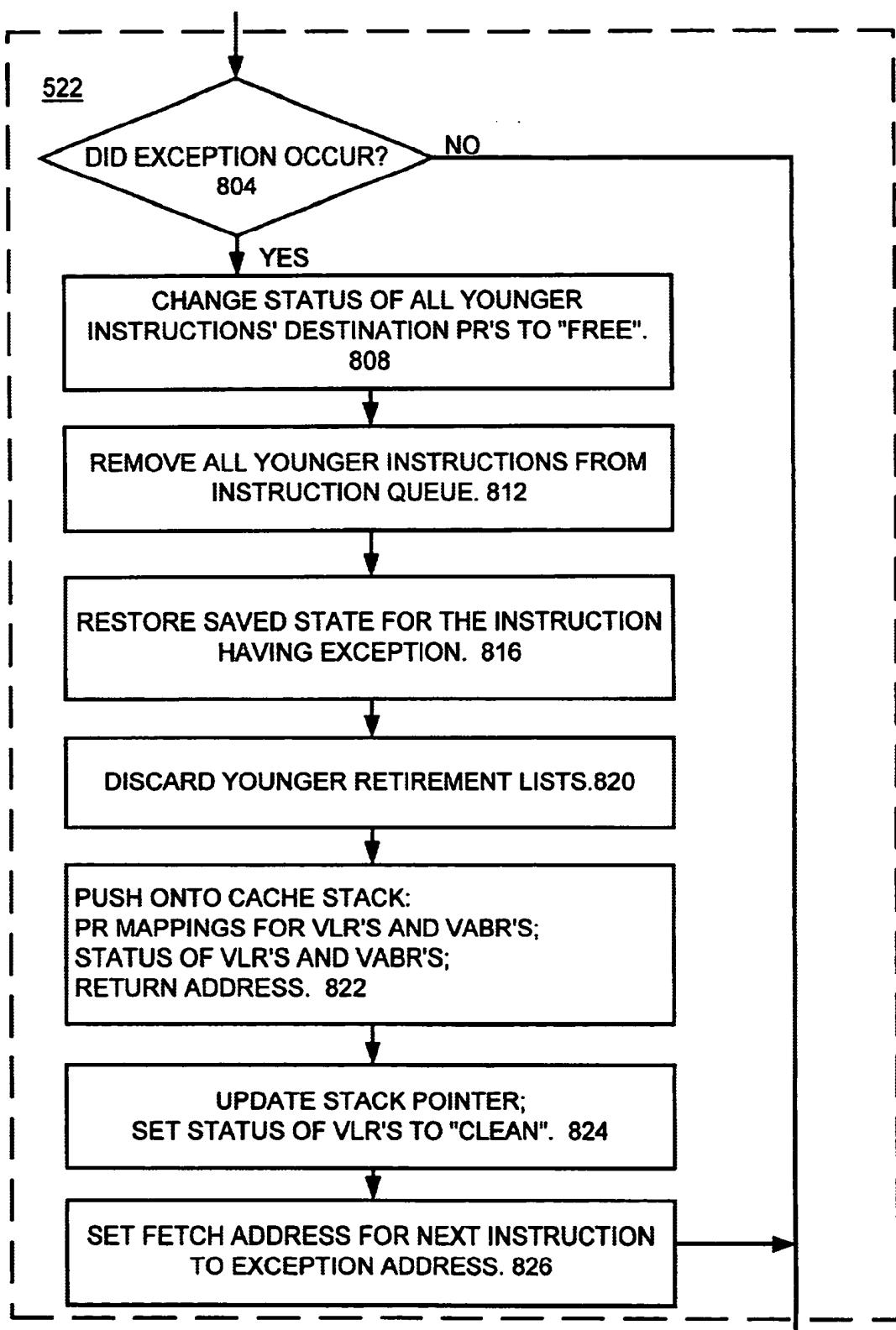
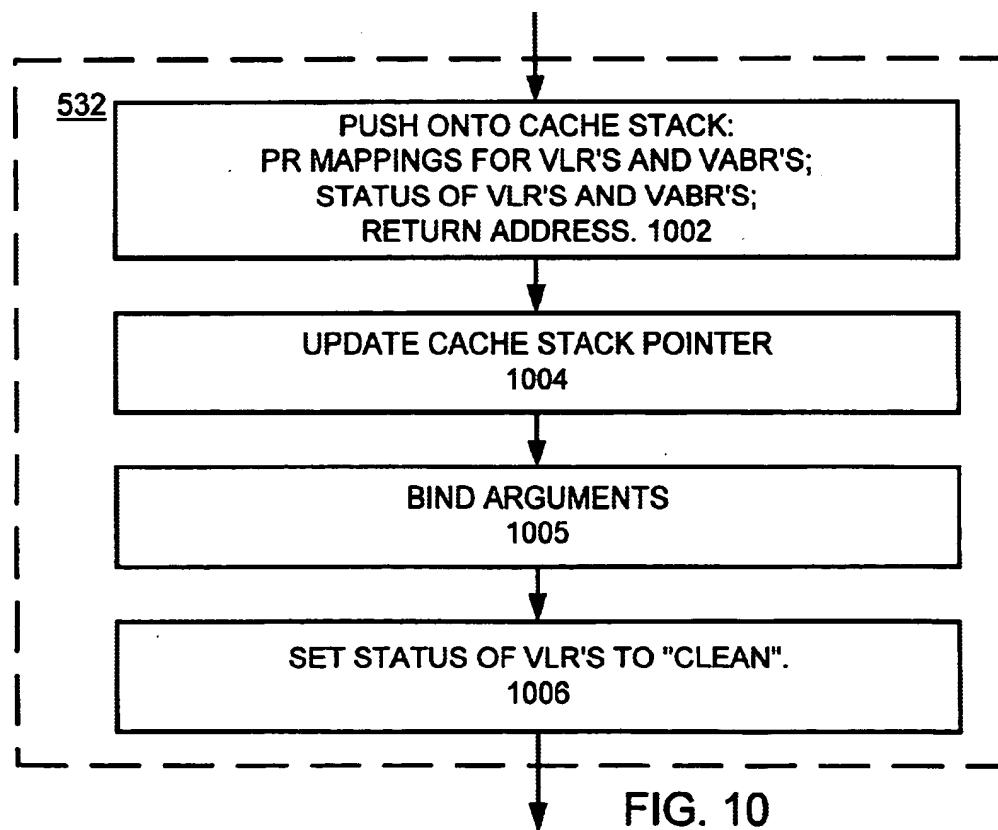
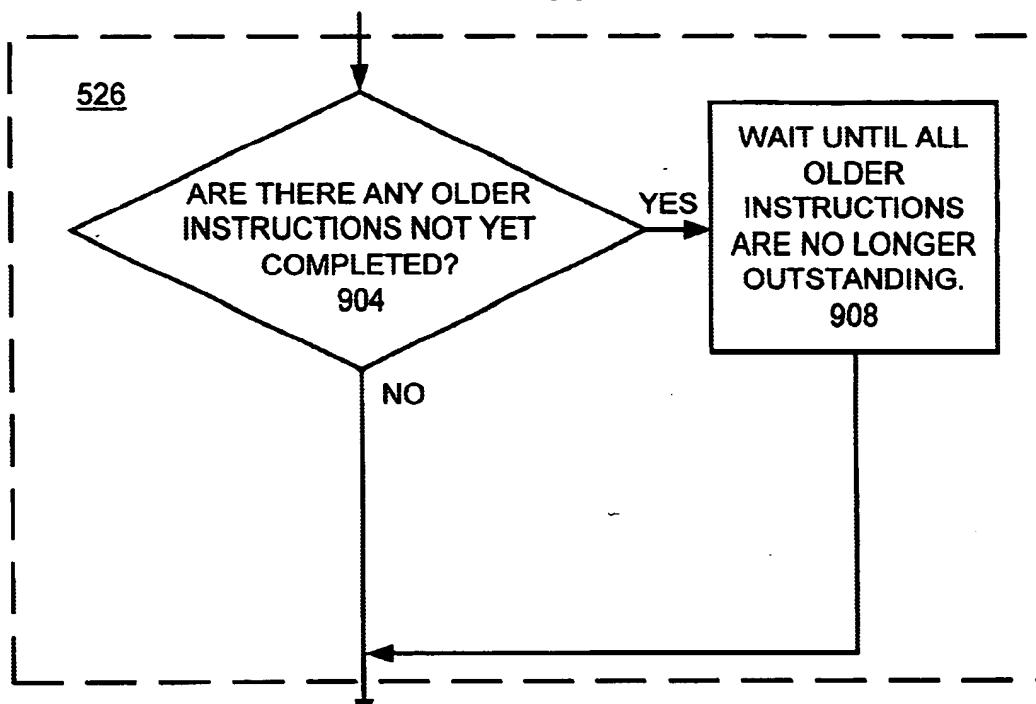


FIG. 8



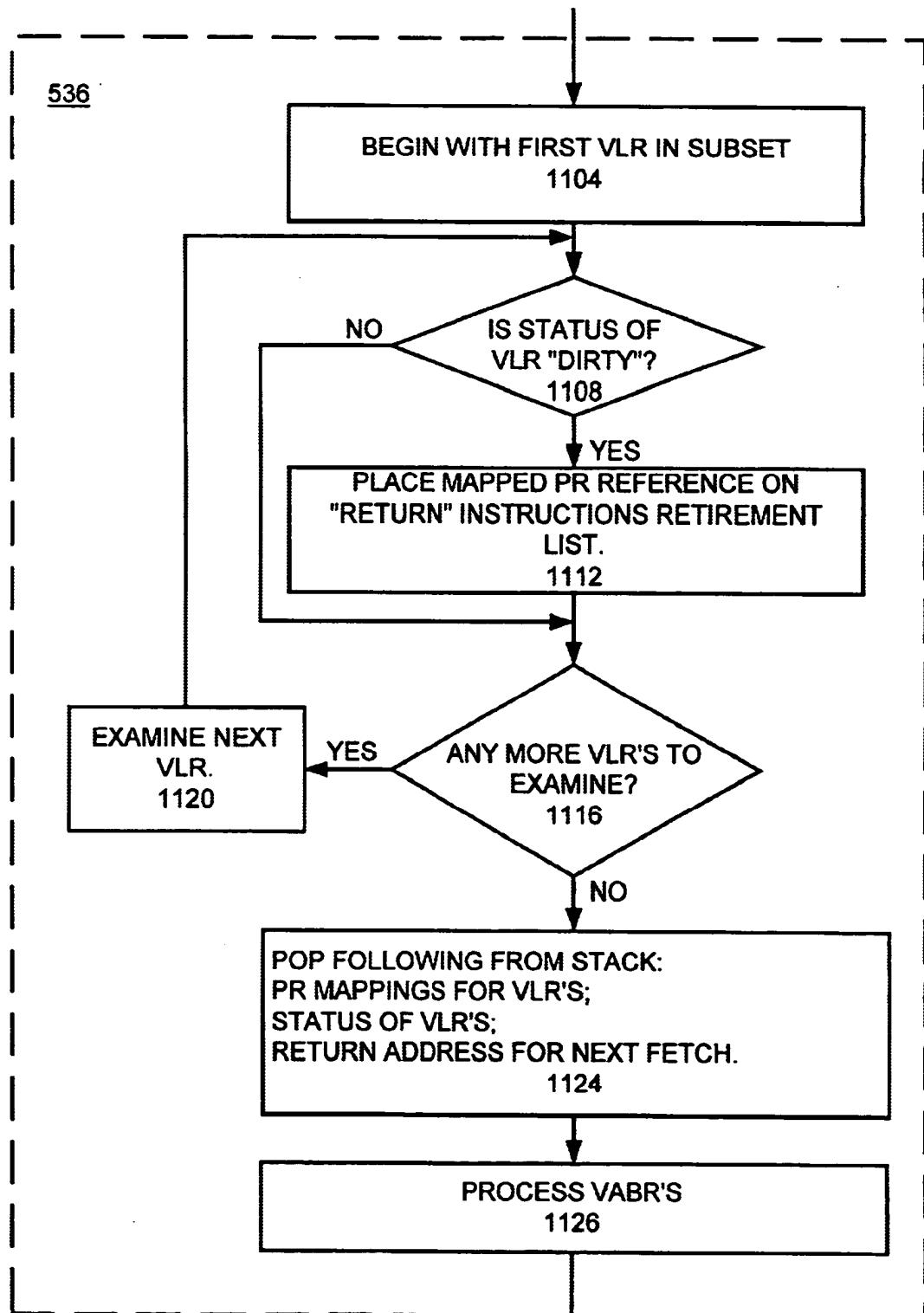


FIG. 11

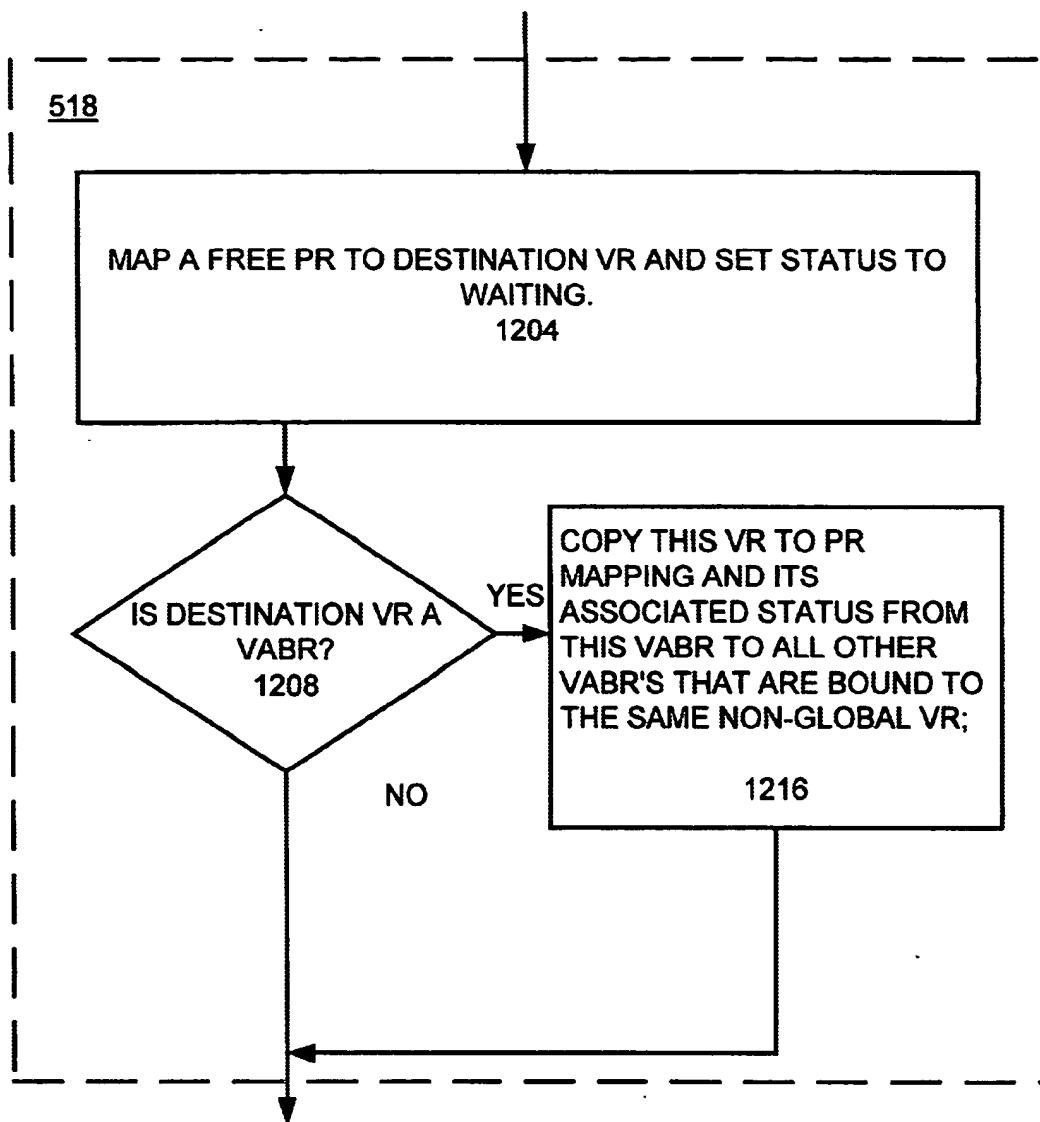
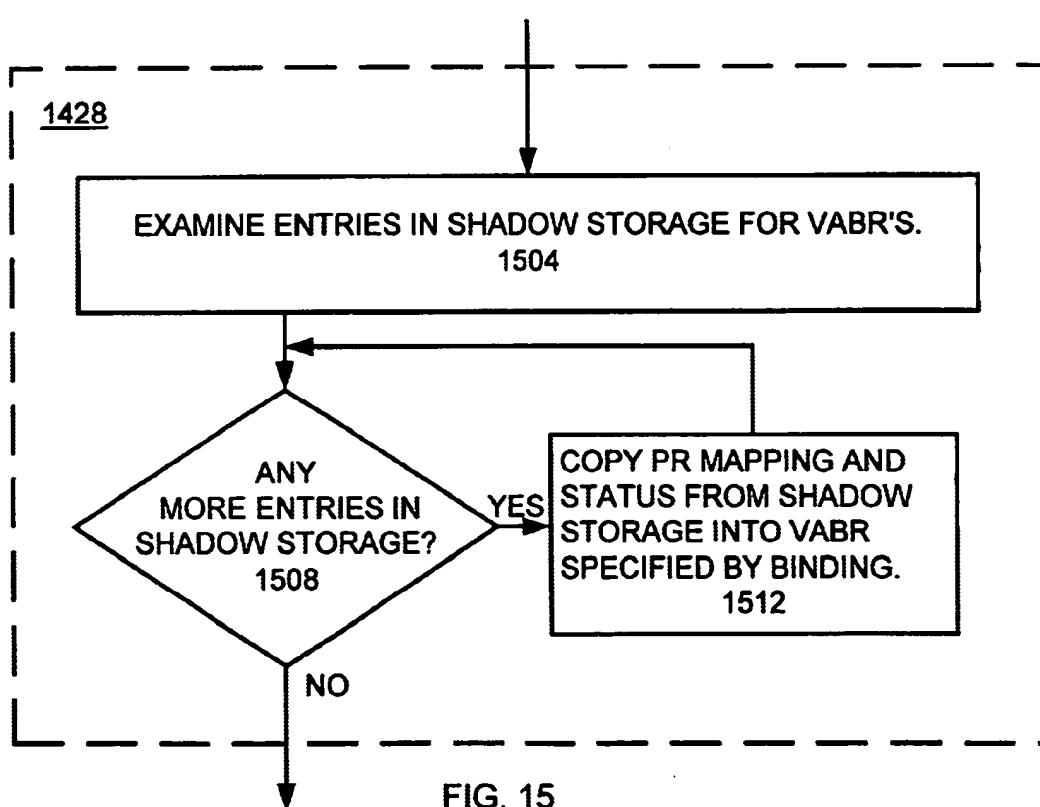
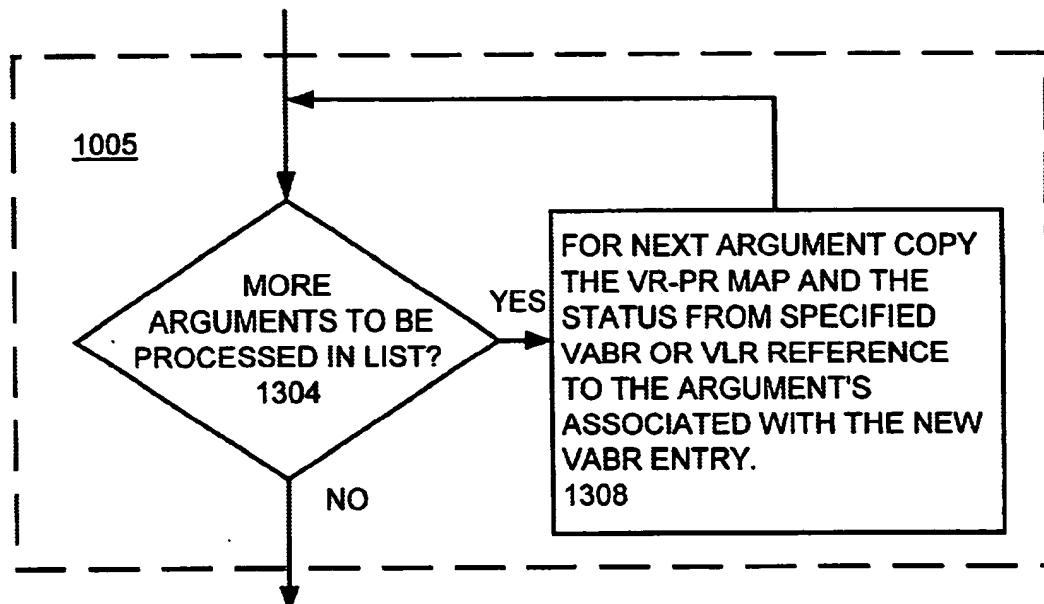


FIG. 12



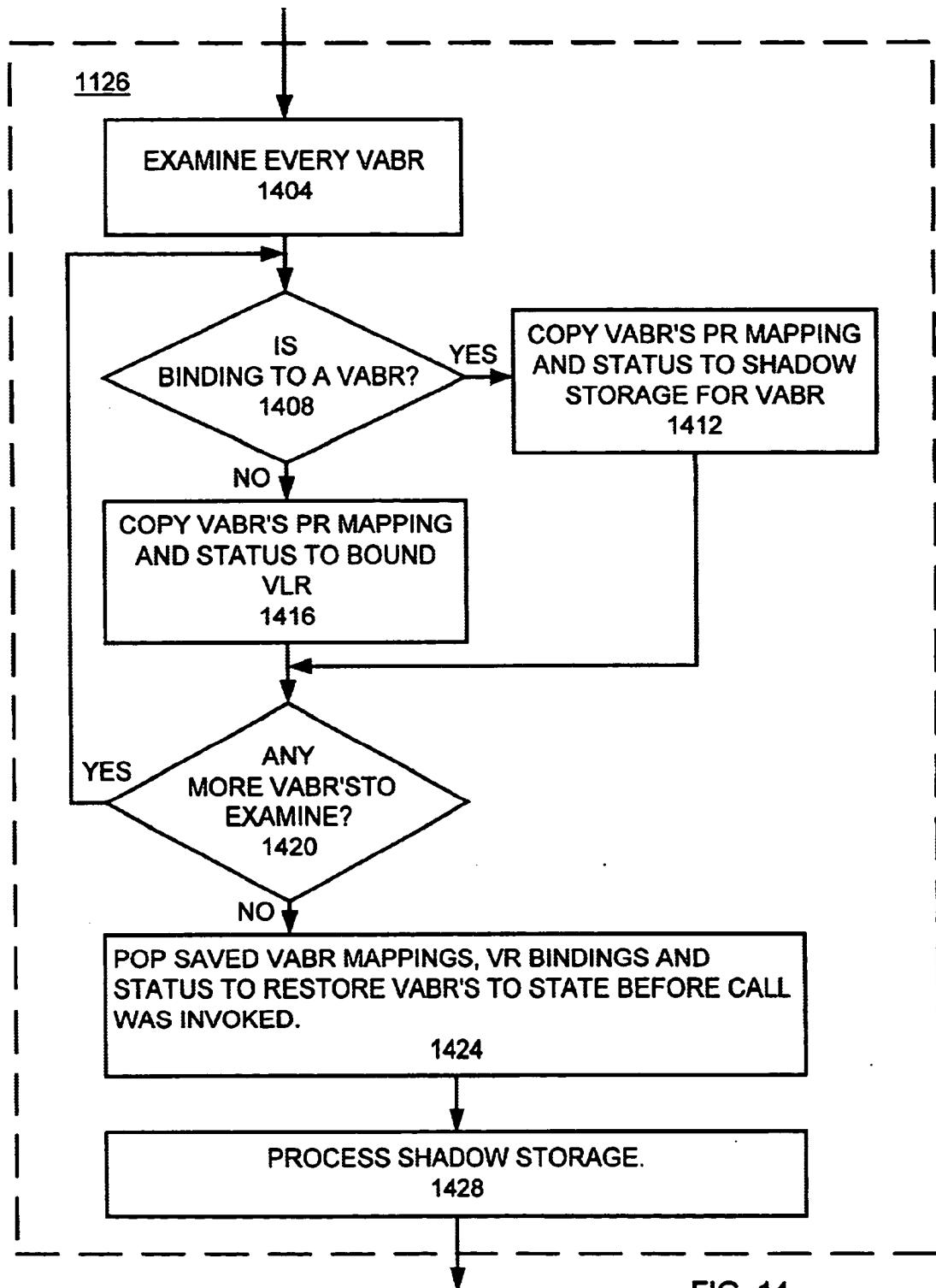
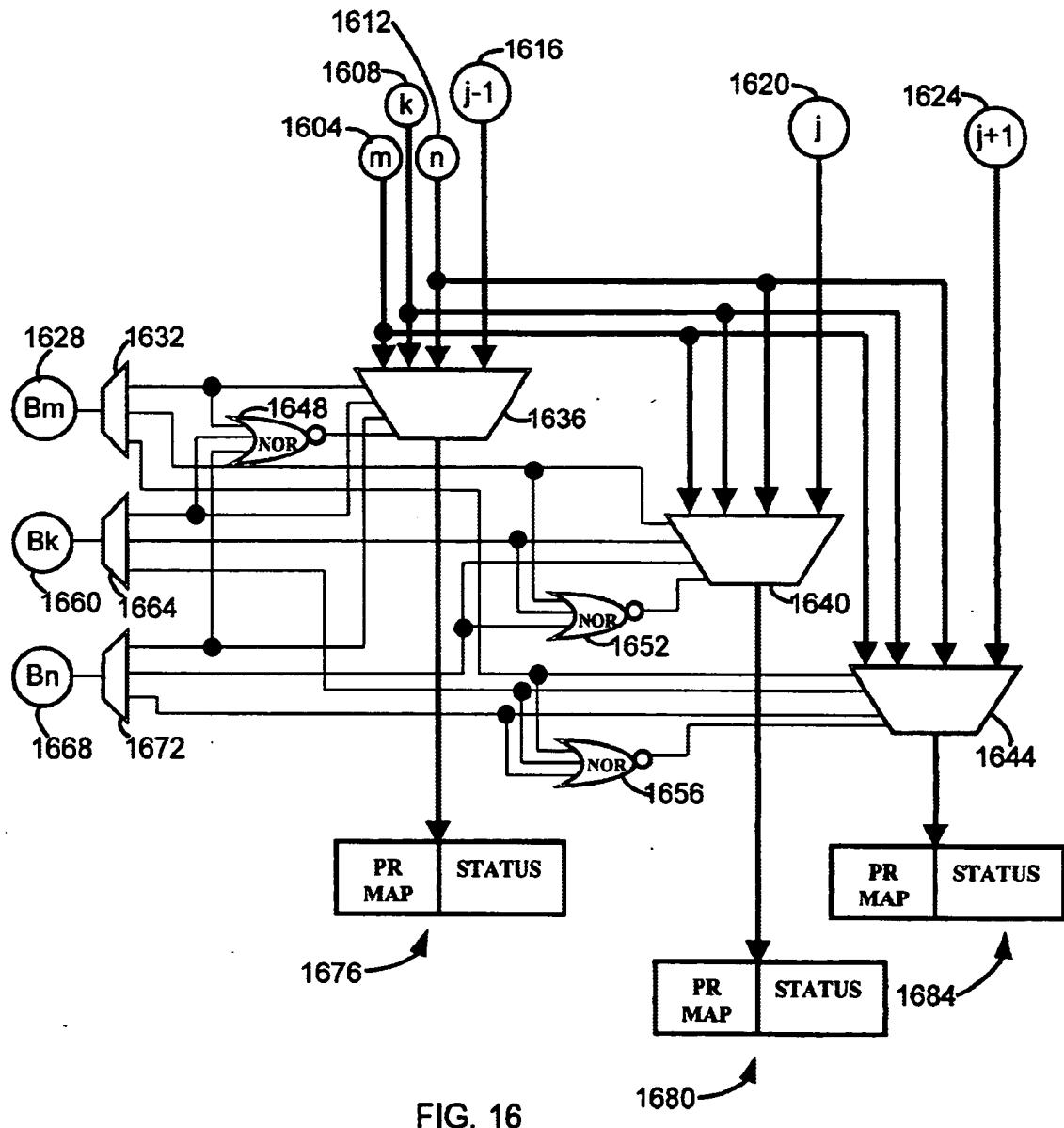
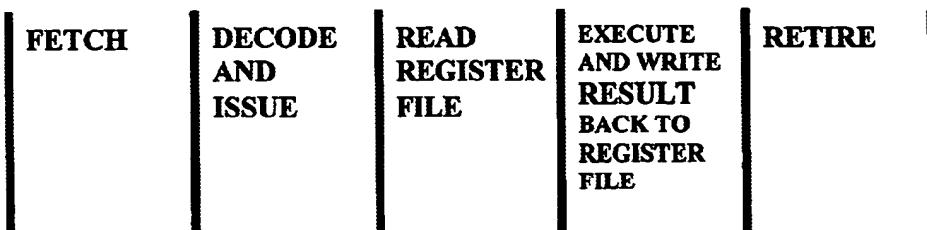


FIG. 14



5 STAGE PIPELINE STAGE**FIG. 17****EXAMPLE PROGRAM**

A: ADD VR6, VR3, VR10
 SUB VR2, VR3, VR8
 MUL VR8, VR1, VR7
 CALL B
 ADD VR8, VR7, VR2
 RET

B: ADD VR1, VR2, VR6
 ADD VR3, VR7, VR7
 MUL VR6, VR7, VR1
 RET

start of example execution

ADD VR0, VR2, VR4
 LIM VR8, #22
 SUB VR3, VR2, VR3
 ADD VR4, VR3, VR3
 MUL VR4, VR5, VR6
 CALL A
 ADD VR8, VR1, VR1
 ADD VR8, VR2, VR2

end of example execution

FIG. 18

CLOCK 1: DECODE STAGE
INITIAL PHYSICAL REGISTER STATE

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	DESCRIPTION
0	0	1	3	EXAMPLE INITIALIZATION
1	0	1	5	EXAMPLE INITIALIZATION
2	0	1	7	EXAMPLE INITIALIZATION
3	0	1	9	EXAMPLE INITIALIZATION
4	0	1	11	EXAMPLE INITIALIZATION
5	0	1	13	EXAMPLE INITIALIZATION
6	0	1	15	EXAMPLE INITIALIZATION
7	0	1	17	EXAMPLE INITIALIZATION
8	0	1	19	EXAMPLE INITIALIZATION
9	0	1	21	EXAMPLE INITIALIZATION
10	0	1	23	EXAMPLE INITIALIZATION
11	0	1	25	EXAMPLE INITIALIZATION
12	0	1	27	EXAMPLE INITIALIZATION
13	0	1	29	EXAMPLE INITIALIZATION
14	0	1	31	EXAMPLE INITIALIZATION
15	0	1	33	EXAMPLE INITIALIZATION
16	1	-	-	UNALLOCATED
17	1	-	-	UNALLOCATED
18	1	-	-	UNALLOCATED
19	1	-	-	UNALLOCATED
20	1	-	-	UNALLOCATED
21	1	-	-	UNALLOCATED
22	1	-	-	UNALLOCATED
23	1	-	-	UNALLOCATED
24	1	-	-	UNALLOCATED
ETC.	1	-	-	UNALLOCATED

FIG. 19

Initial Mapping States

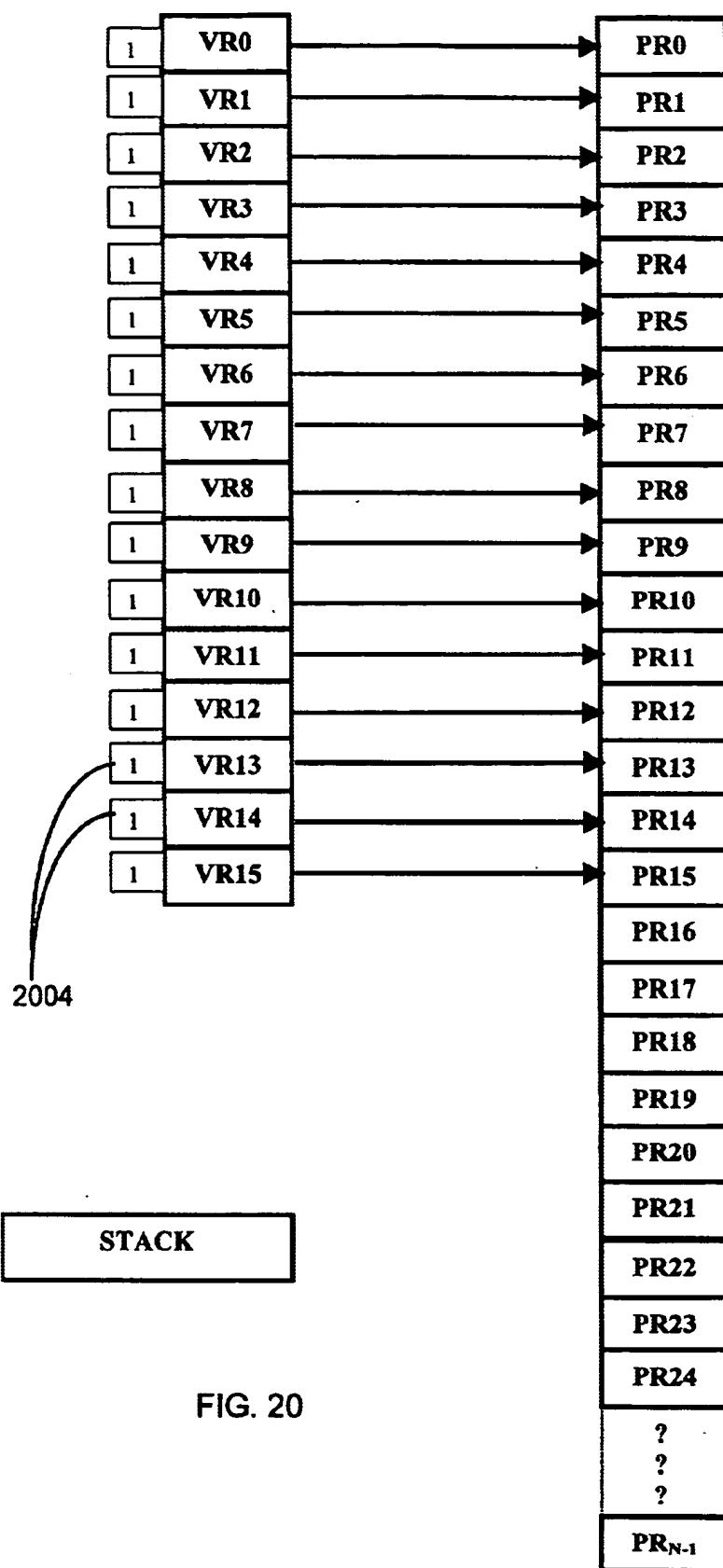


FIG. 20

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INSTRUCTION NUMBER	INSTRUCTION	DESCRIPTION	EFFECT OF INSTRUCTION
1	ADD VR0, VR2, VR4	VR0 + VR2 → VR4	10 → VR4
2	LIM VR8, #22	22 → VR8	22 ₁₀ → VR8
3	SUB VR3, VR2, VR3	VR3 - VR2 → VR3	2 → VR3
4	ADD VR4, VR3, VR3	VR4 + VR3 → VR3	12 → VR3
5	MUL VR4, VR5, VR6	VR4 * VR5 → VR6	130 → VR6
6	CALL A	CALL subroutine A	VR6—VR9 available as scratch registers
7	ADD VR6, VR3, VR10	VR6 + VR3 → VR10	142 → VR10
8	SUB VR2, VR3, VR8	VR2 - VR3 → VR8	-5 → VR8 (use VR8 as scratch register)
9	MUL VR8, VR1, VR7	VR8 * VR1 → VR7	-25 → VR7 (use VR7 as scratch register)
10	CALL B	CALL subroutine B	VR6—VR9 available as scratch registers
11	ADD VR1, VR2, VR6	VR1 + VR2 → VR6	12 → VR6 (use VR6 as scratch register)
12	ADD VR3, VR7, VR7	VR3 + VR7 → VR7	-13 → VR7 (use VR7 as scratch register)
13	MUL VR6, VR7, VR1	VR6 * VR7 → VR1	-156 → VR1
14	RET	RETURN	restore value of 130 to VR6 and -25 to VR7
15	ADD VR8, VR7, VR1	VR8 + VR7 → VR2	-30 → VR2
16	RET	RETURN	restore value of 17 to VR7 and 22 to VR8
17	ADD VR8, VR1, VR1	VR8 + VR1 → VR1	-134 → VR1
18	ADD VR8, VR2, VR2	VR8 + VR2 → VR2	-8 → VR2

EXAMPLE INSTRUCTION FLOW

FIG. 21

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	INSTRUCTION	VIRTUAL REGISTER NUMBER:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NUMBER	INSTRUCTION	INITIAL VALUE:	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33
1	ADD VR0, VR2, VR4	3	5	7	9	10	13	15	17	19	21	23	25	27	29	31	33	
2	LJM VR8, #22	3	5	7	9	10	13	15	17	22	21	23	25	27	29	31	33	
3	SUB VR3, VR2, VR3	3	5	7	2	10	13	15	17	22	21	23	25	27	29	31	33	
4	ADD VR4, VR3, VR3	3	5	7	12	10	13	15	17	22	21	23	25	27	29	31	33	
5	MUL VR4, VR5, VR6	3	5	7	12	10	13	130	17	22	21	23	25	27	29	31	33	
6	CALL A	3	5	7	12	10	13	130	17	22	21	23	25	27	29	31	33	
7	ADD VR6, VR3, VR10	3	5	7	12	10	13	130	17	22	21	142	25	27	29	31	33	
8	SUB VR2, VR3, VR8	3	5	7	12	10	13	130	17	-5	21	142	25	27	29	31	33	
9	MUL VR8, VR1, VR7	3	5	7	12	10	13	130	-25	-5	21	142	25	27	29	31	33	
10	CALL B	3	5	7	12	10	13	130	-25	-5	21	142	25	27	29	31	33	
11	ADD VR1, VR2, VR6	3	5	7	12	10	13	12	-25	-5	21	142	25	27	29	31	33	
12	ADD VR3, VR7, VR7	3	5	7	12	10	13	12	-13	-5	21	142	25	27	29	31	33	
13	MUL VR6, VR7, VR1	3	-156	7	12	10	13	12	-13	-5	21	142	25	27	29	31	33	
14	RET	3	-156	7	12	10	13	130	-25	-5	21	142	25	27	29	31	33	
15	ADD VR8, VR7, VR1	3	-156	-30	12	10	13	130	-25	-5	21	142	25	27	29	31	33	
16	RET	3	-156	-30	12	10	13	130	17	22	21	142	25	27	29	31	33	
17	ADD VR8, VR1, VR1	3	-134	-30	12	10	13	130	17	22	21	142	25	27	29	31	33	
18	ADD VR8, VR2, VR2	3	-134	-8	12	10	13	130	17	22	21	142	25	27	29	31	33	

CONTENTS OF VIRTUAL REGISTERS AS INSTRUCTIONS EXECUTE

FIG. 22

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<u>Clock 1</u>	Fetch instr. 1,2;			
<u>Clock 2</u>	Fetch instr. 3,4; Decode instr. 1, 2.			
<u>Clock 3</u>	Fetch instr. 5,6; Decode instr. 3,4; Read regs. PR0, PR2 for instr. 1.	Read regs. PR2, PR3 for instr. 3; respectively. Execute instr. 6 (CALL A).	Execute instr. 1, 2 and store results in PR16, PR17	
<u>Clock 4</u>	Fetch instr. 7,8; Decode instr. 5,6; Read regs. PR5, PR16 for instr. 5;	Read regs. PR5, PR16 for instr. 5;	Execute instr. 3; store result in PR18. Retire instr. 1,2.	
<u>Clock 5</u>	Fetch instr. 9,10; Decode instr. 7,8; Read regs. PR16, PR18 for instr. 4;	Read regs. PR16, PR18 for instr. 4;	Execute instr. 5 and store result in PR20;	
<u>Clock 6</u>	Fetch instr. 11,12; Decode instr. 9,10; Read regs. PR16, PR18 for instr. 4;	Read regs. PR16, PR18 for instr. 4;	Execute instr. 10 (CALL B); Retire instr. 3.	
<u>Clock 7</u>	Fetch instr. 13,14; Decode instr. 11,12;		Execute instr. 4 and store result in PR19.	
<u>Clock 8</u>	Fetch instr. 15,16; Decode instr. 13,14;	Read regs. PR2, PR19, PR20 for instr. 7, 8;	Execute instr. 14(Return). Retire instr. 4, 5, 6.	
<u>Clock 9</u>	Fetch instr. 17,18; Decode instr. 15,16;	Read regs. PR1, PR2, PR19 for instr. 9 and 11;	Execute instr. 7 and 8 and store results in PR21 and PR22 respectively. Execute instr. 16(Return).	

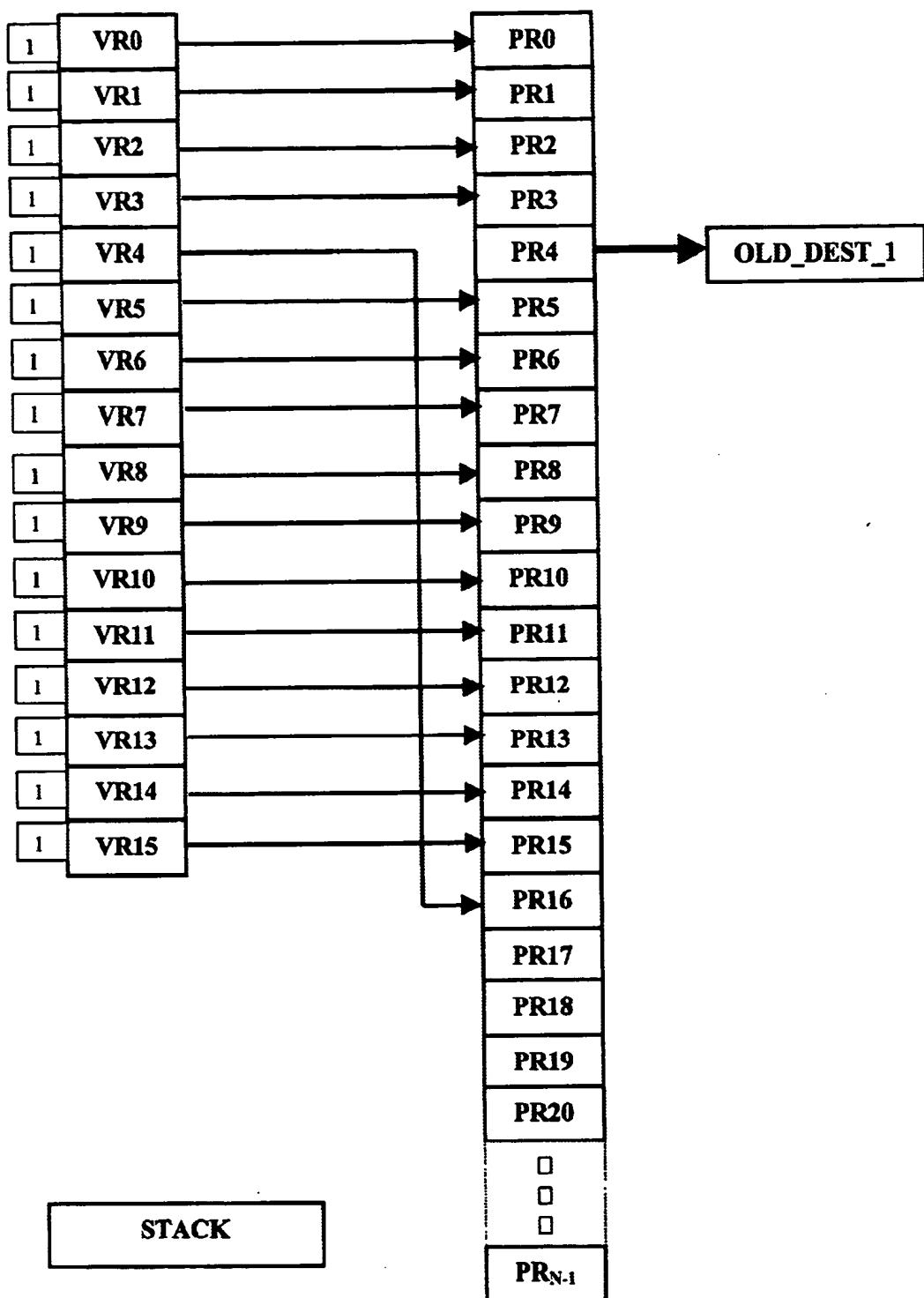
Clock by Clock Pipeline Description**FIG. 23A**

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<u>Clock 10</u>	Decode instr. 17, 18;	Execute instr. 9 and 11 and store results in PR4 and PR8 respectively.
<u>Clock 11</u>	Read regs. PR4, PR19, PR22 for instr. 12 and 15;	Retire instr. 9, 10, 11.
<u>Clock 12</u>	Read regs. PR2, PR6, PR17 for instr. 17 and 18;	Execute instr. 12, 15 and store results in PR3 and PR6 respectively.
<u>Clock 13</u>	Read regs. PR3, PR8 for instr. 13;	Execute instr. 17, 18 and store results in PR18 and PR24 respectively; Retire instr. 12.
<u>Clock 14</u>		Execute instr. 13 and store results in PR23.
<u>Clock 15</u>		Retire instr. 13, 14, 15, 16, 17, 18.

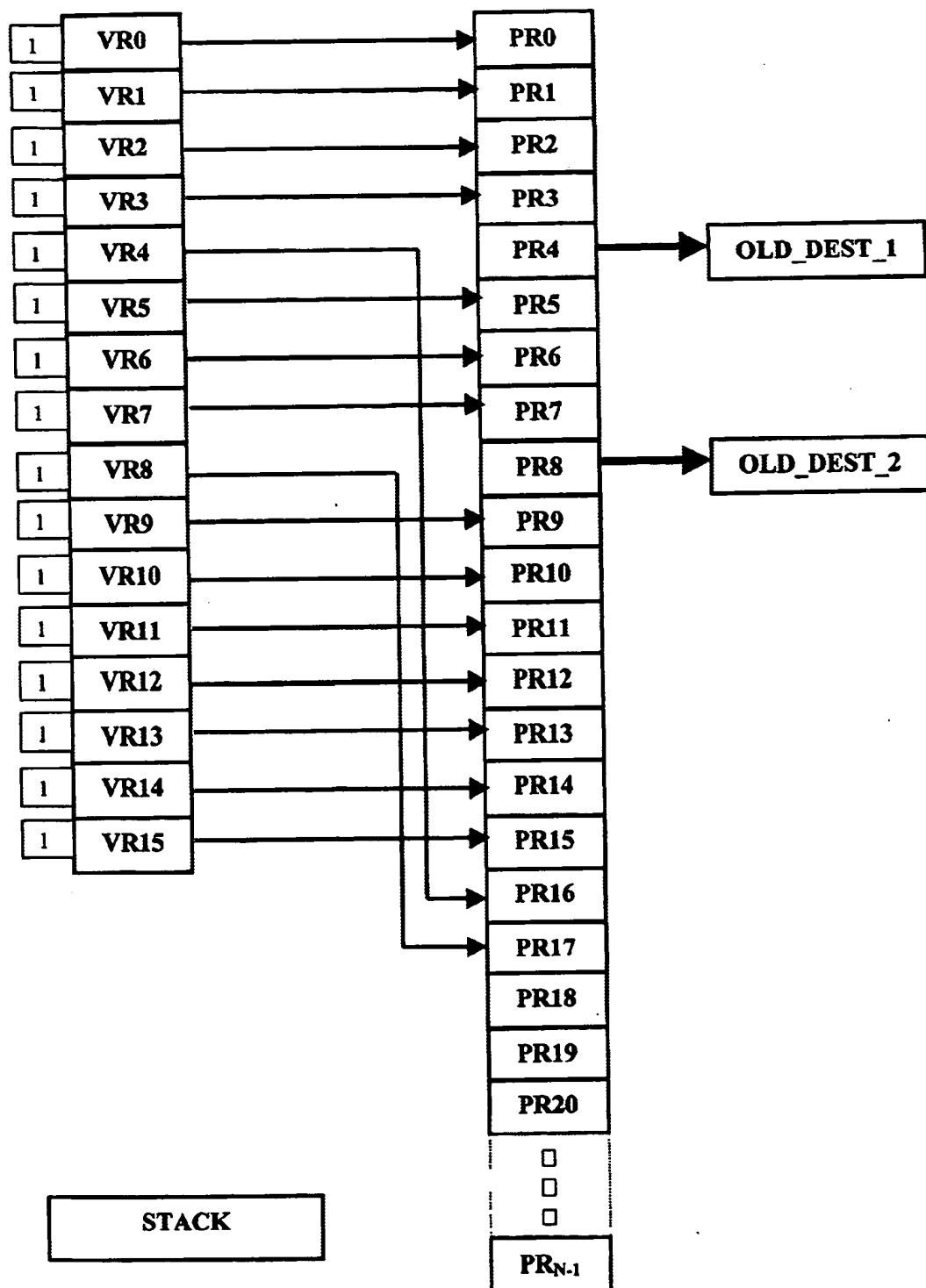
Clock by Clock Pipeline Description

FIG. 23B



INSTR. 1: ADD VR0, VR2, VR4 maps to $PR0 + PR2 \rightarrow PR16,$
 $PR4 \rightarrow OLD_DEST_1$

FIG. 24



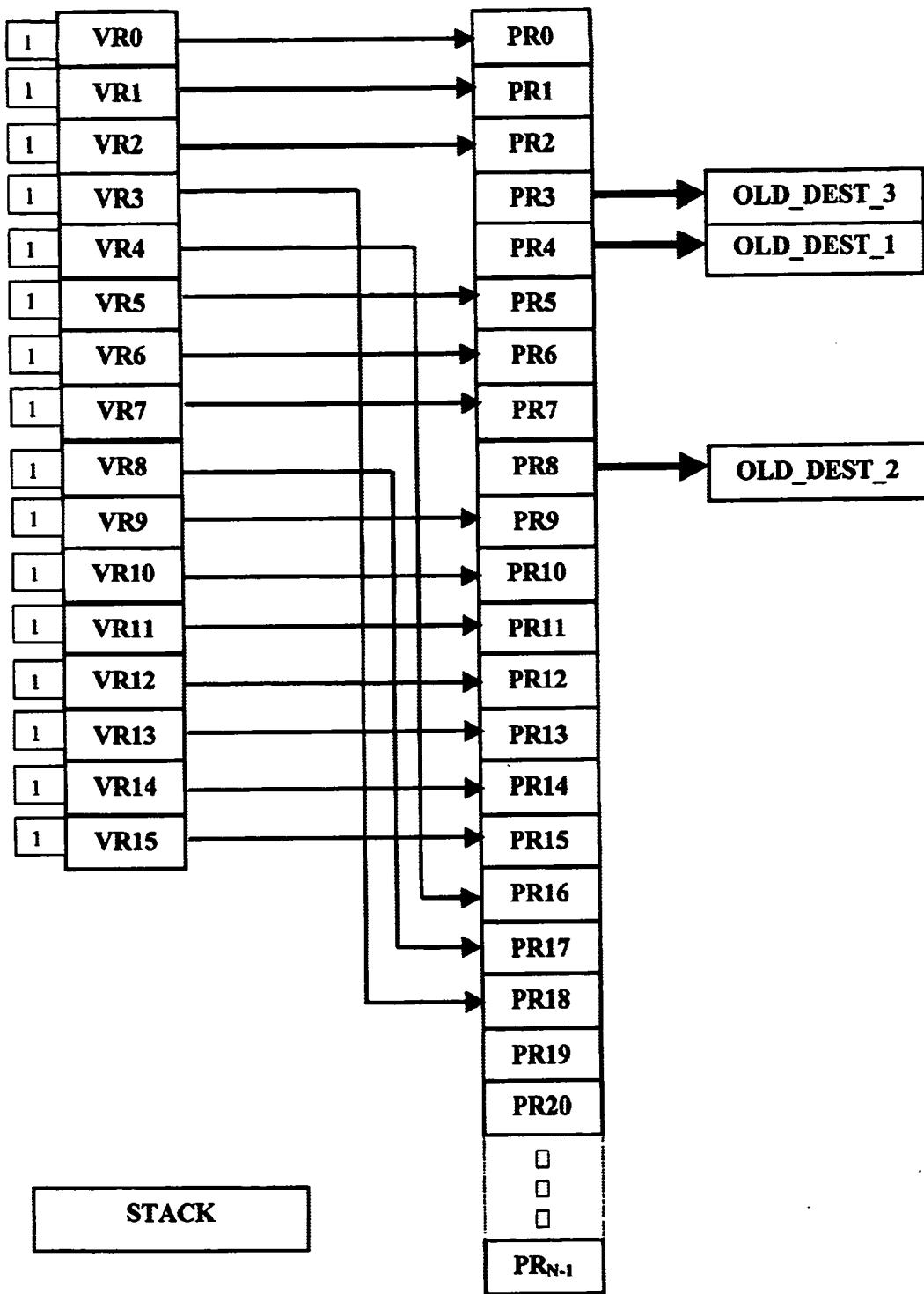
INSTR. 2: LIM VR8, #22 maps to LIM PR17, #22, PR8 → OLD_DEST_2

FIG. 25

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	1	9	3	EXAMPLE INITIALIZATION
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	6	EXAMPLE INITIALIZATION
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	0	-	4	WAITING FOR INSTRUCTION 1 TO EXECUTE
17	0	0	-	8	WAITING FOR INSTRUCTION 2 TO EXECUTE
18	1	-	-	-	UNALLOCATED
19	1	-	-	-	UNALLOCATED
20	1	-	-	-	UNALLOCATED
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

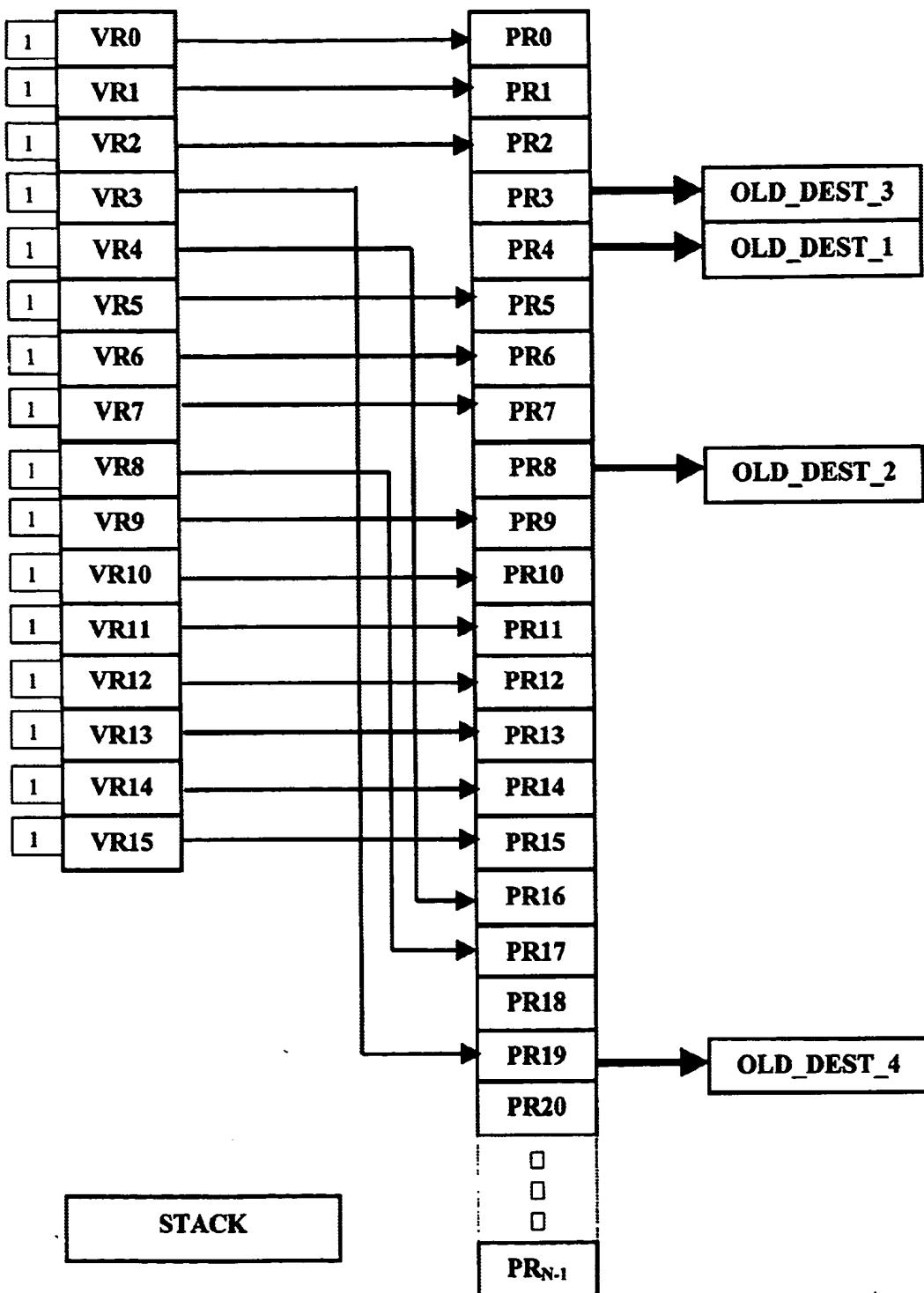
**CLOCK 2: DECODE STAGE
INSTRUCTIONS 1 & 2 PHYSICAL REGISTER STATE**

FIG. 26



INSTR. 3: SUB VR3, VR2, VR3 maps to SUB PR3, PR2, PR18,
 $PR3 \rightarrow OLD_DEST_3$

FIG. 27



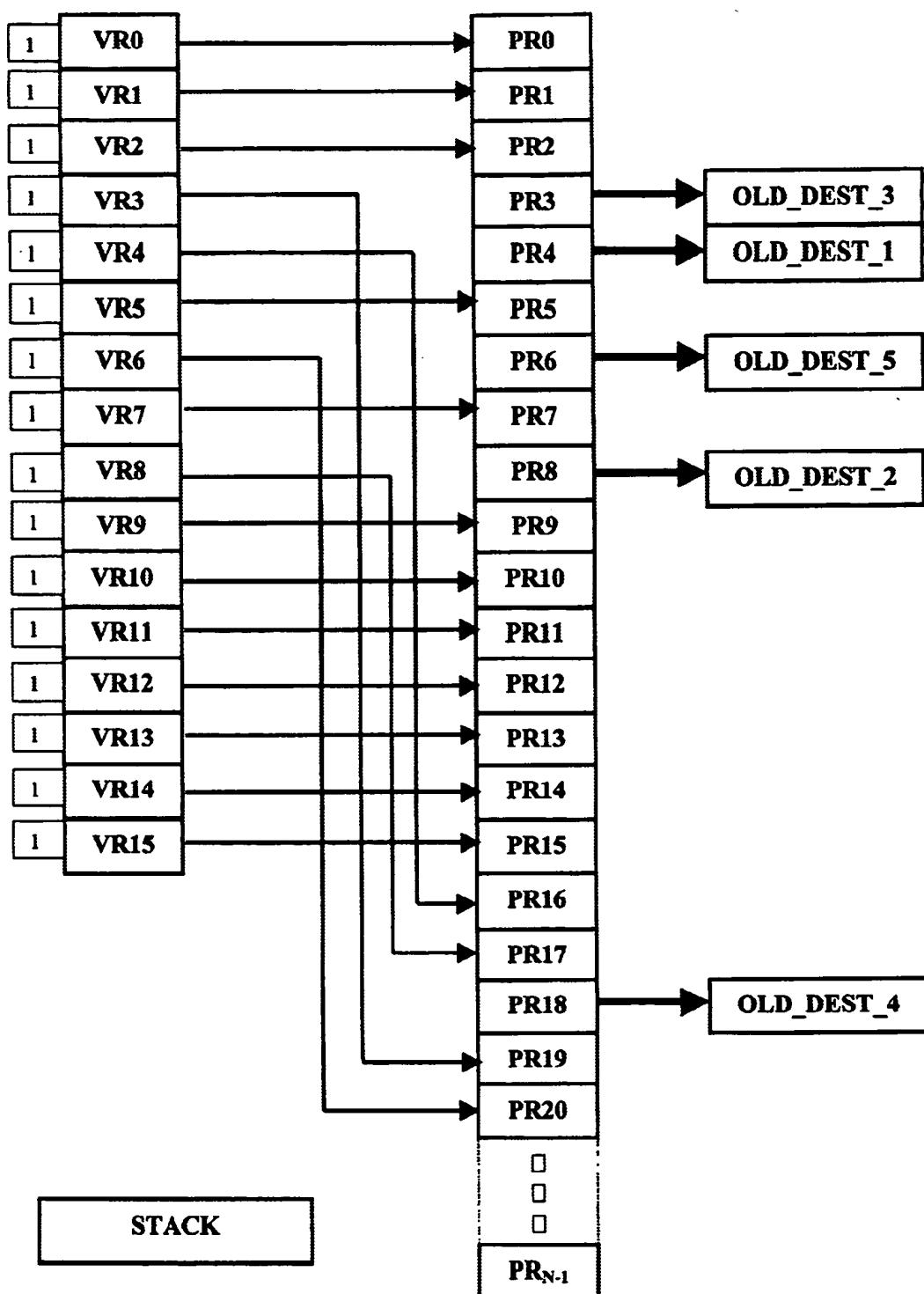
**INSTR. 4: ADD VR4, VR3, VR3 maps to ADD PR16, PR18, PR19,
PR18 → OLD_DEST_4**

FIG. 28

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	6	EXAMPLE INITIALIZATION
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	0	-	4	WAITING FOR INSTRUCTION 1 TO EXECUTE
17	0	0	-	8	WAITING FOR INSTRUCTION 2 TO EXECUTE
18	1	-	-	-	WAITING FOR 3 TO EXECUTE & RETIRE
19	1	-	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	1	-	-	-	UNALLOCATED
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

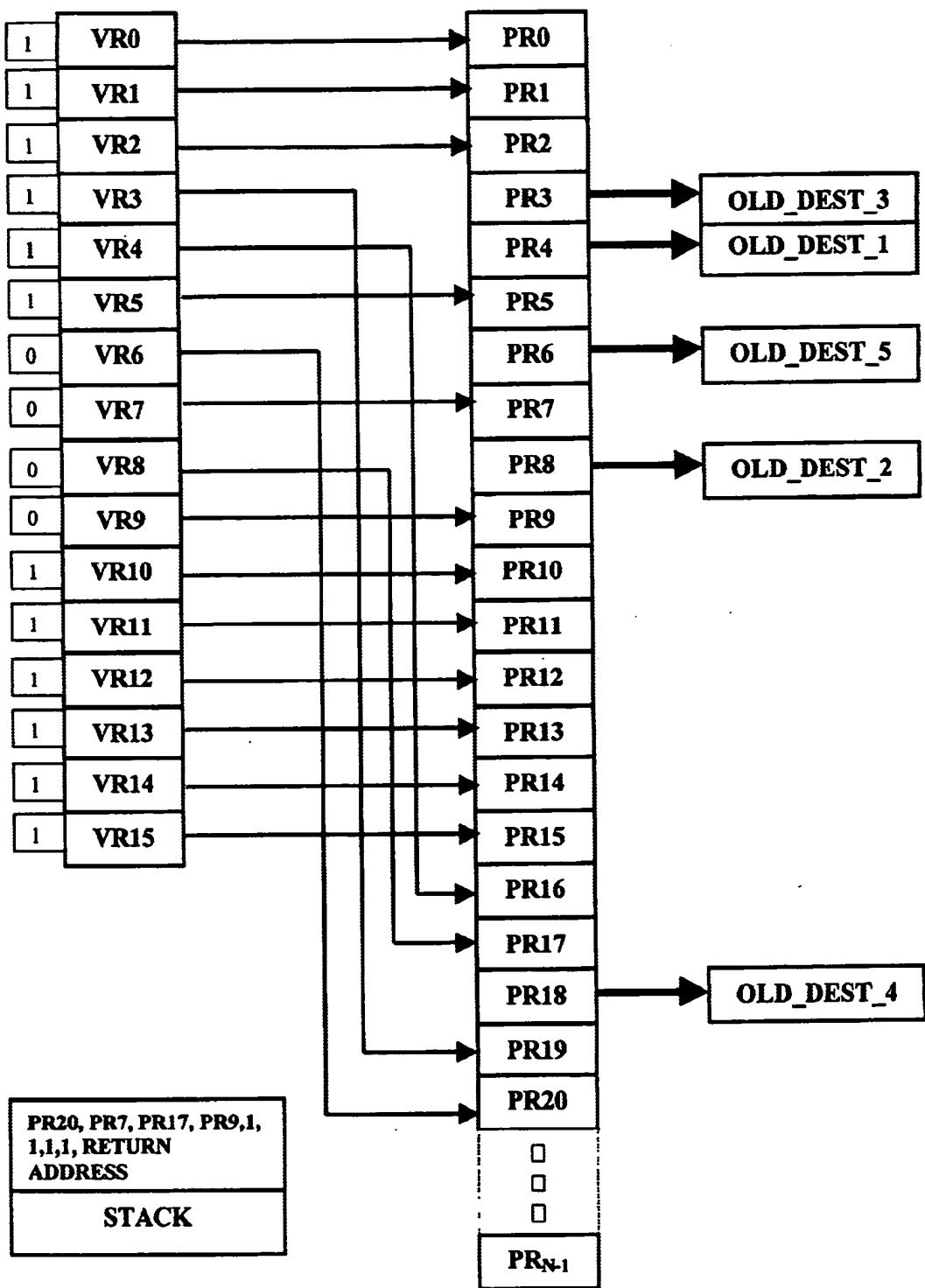
**CLOCK 3: DECODE STAGE
INSTRUCTIONS 3 & 4 PHYSICAL REGISTER STATE**

FIG. 29



INSTR. 5: MUL VR4, VR5, VR6 maps to MUL PR16, PR5, PR20,
 $PR6 \rightarrow OLD_DEST_5$

FIG. 30



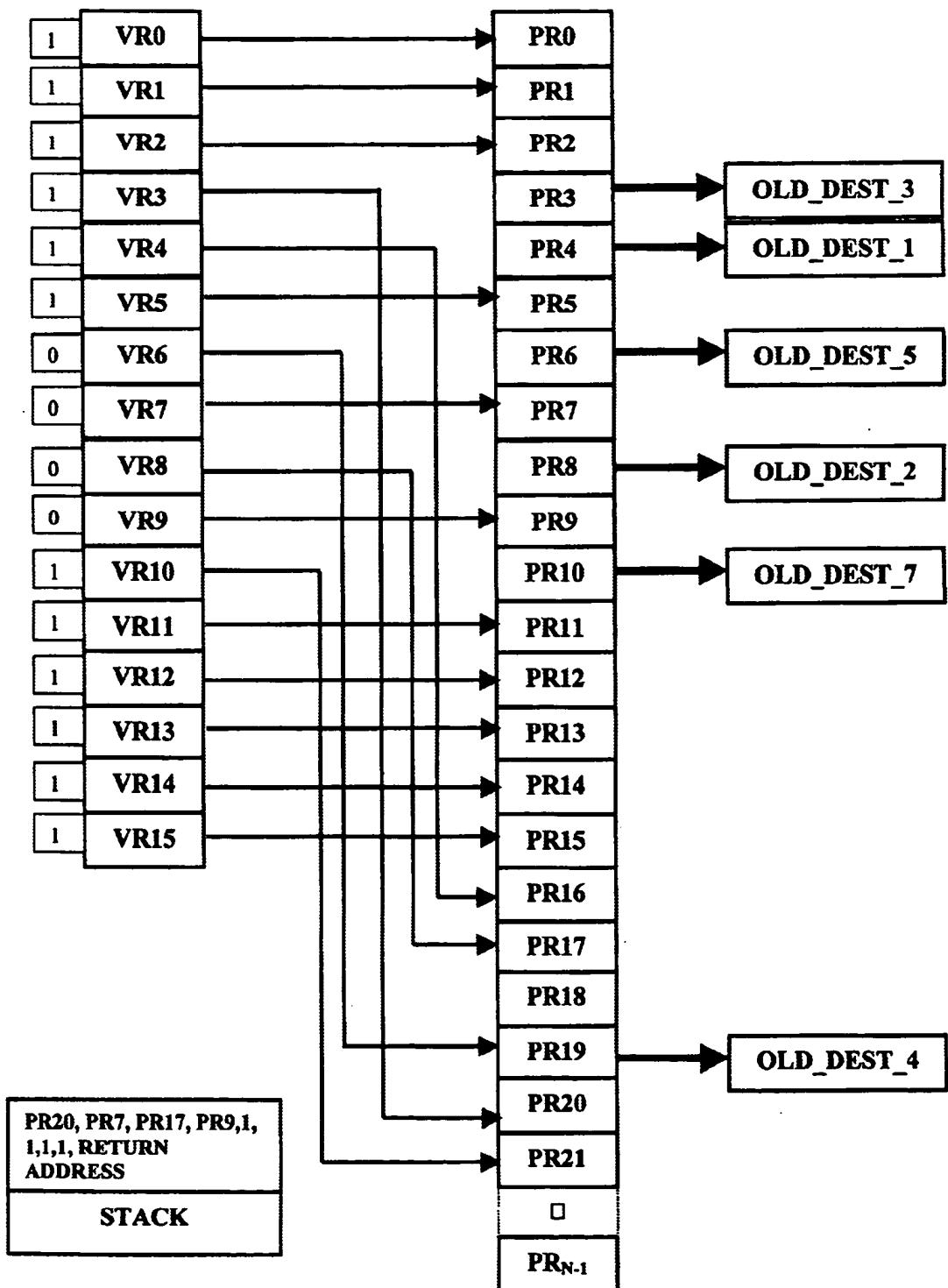
INSTR. 6: CALL A actionPUSH PR20, PR7, PR17, PR9, 1, 1, 1, 1, RETURN ADDRESS, 0000 → DIRTY BITS FOR VR6-9, transfer to A

FIG. 31

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	INSTRUCTION 2 EXECUTED
18	0	-	-	-	WAITING FOR INST. 3 TO EXECUTE & RETIRE
19	0	-	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	-	-	6	WAITING FOR INSTRUCTION 5 TO EXECUTE
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 4: DECODE STAGE
INSTRUCTIONS 5 & 6 PHYSICAL REGISTER STATE**

FIG. 32



INSTR. 7: ADD VR6, VR3, VR10 maps to ADD PR20, PR19, PR21,
PR10 → OLD_DEST_7

FIG. 33

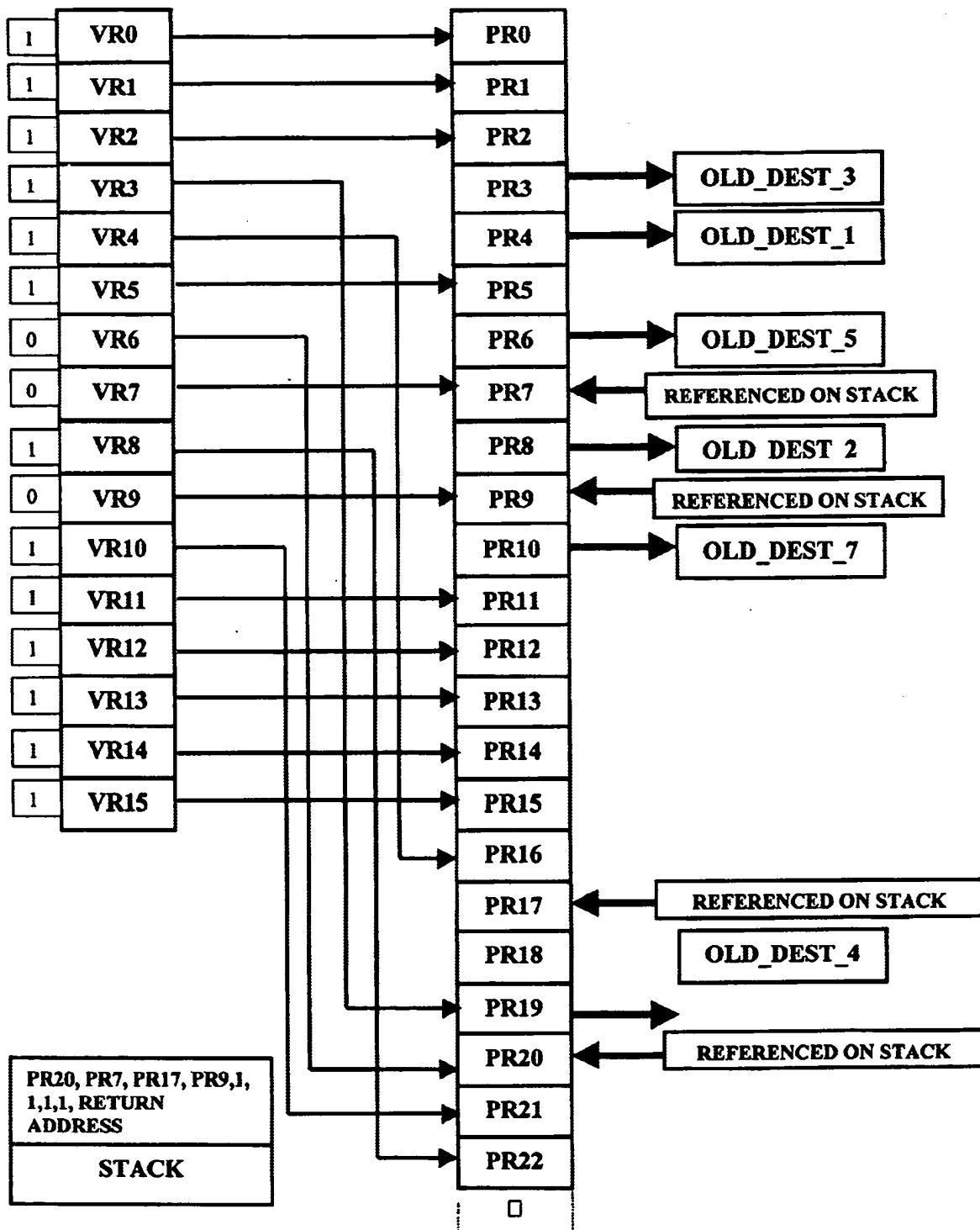
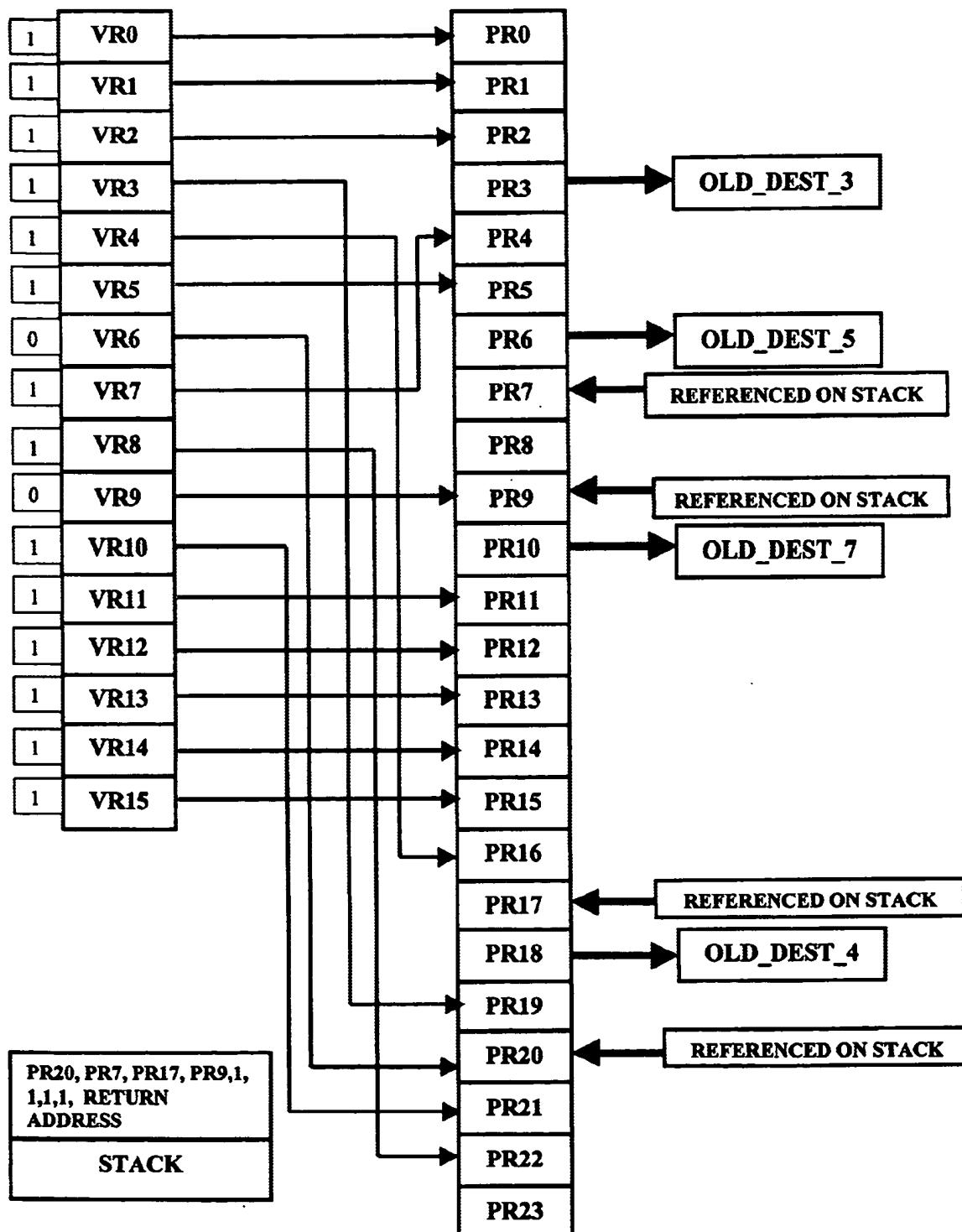


FIG. 34

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	1	-	-	-	INSTRUCTION 1 RETIRED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	7	EXAMPLE INITIALIZATION
8	1	-	-	-	INSTRUCTION 2 RETIRED
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INSTRUCTION 2 EXECUTED
18	0	1	2	-	INS. 3 EXECUTED WAITING FOR 4 TO RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	0	-	6	WAITING FOR INSTRUCTION 5 TO EXECUTE
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

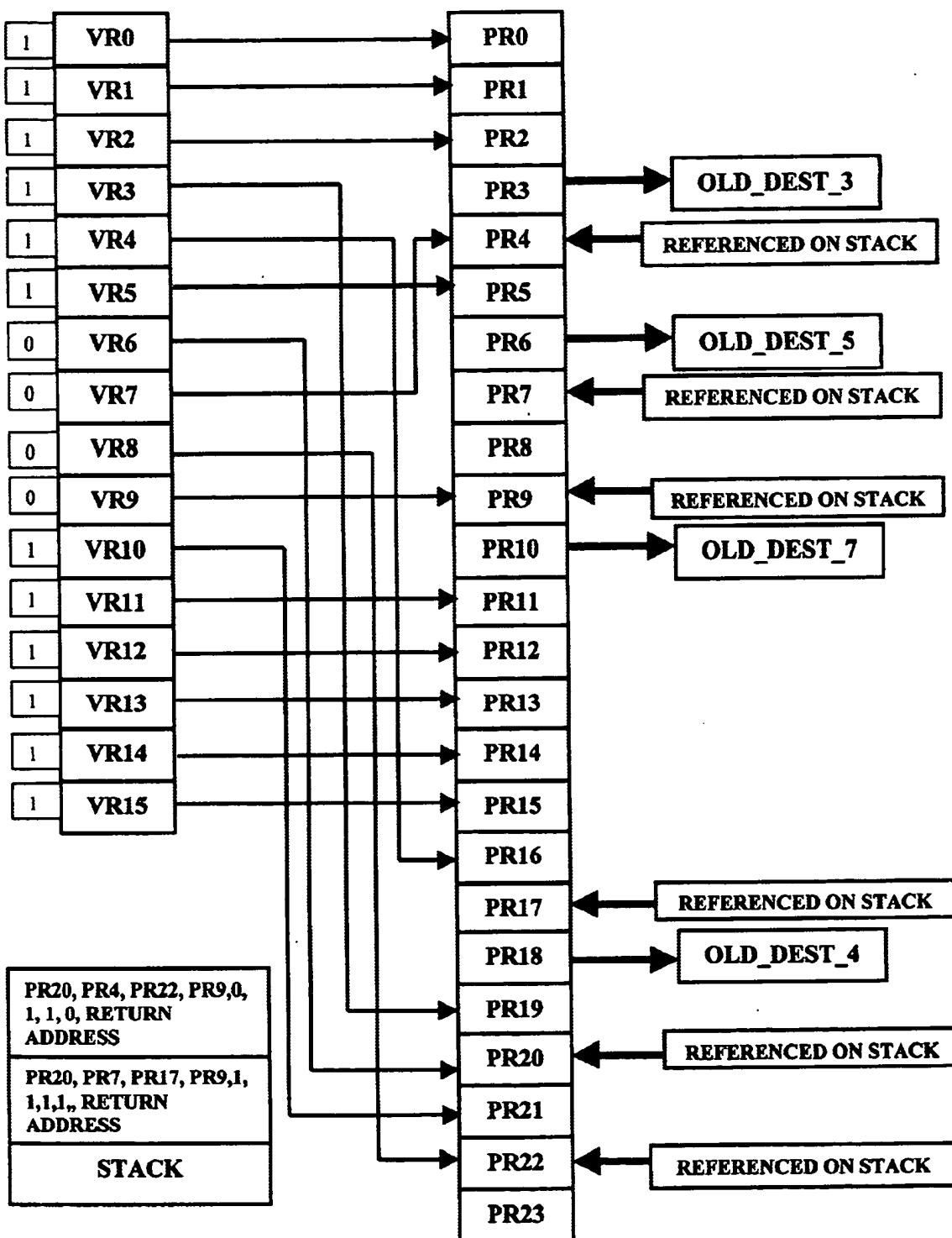
CLOCK 5: DECODE STAGE
INSTRUCTIONS 7 & 8 PHYSICAL REGISTER STATE

FIG. 35



INSTR. 9: MUL VR8, VR1, VR7 maps to MUL PR22, PR1, PR4
1 → DIRTY BIT FOR VR7

FIG. 36



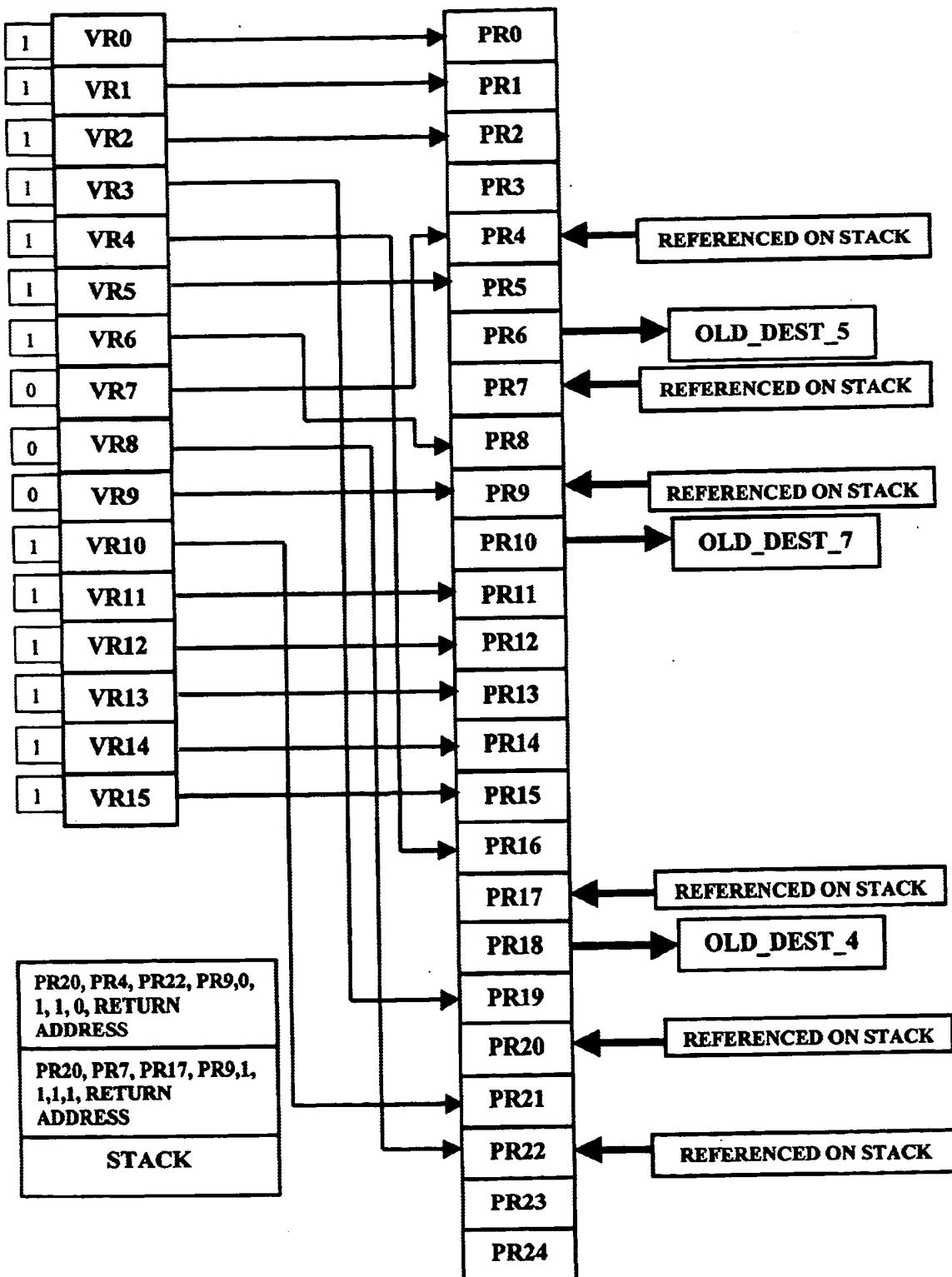
INSTR. 10: CALL B actionPUSH PR20, PR4, PR22, PR9, 0, 1, 1, 0,
RETURN ADDRESS, 0000 → DIRTY BITS FOR VR6-9, transfer to B

FIG. 37

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	1	-	-	-	INSTRUCTION 3 RETIRED
4	0	0	-	7	WAITING FOR INSTRUCTION 9 TO EXECUTE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	-	REFERENCE PREVIOUSLY SAVED ON STACK
8	1	-	-	-	UNALLOCATED
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INSTRUCTION 2 EXECUTED
18	0	1	2	-	WAITING FOR INSTRUCTION 4 TO RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	1	130	6	INSTRUCTION 5 EXECUTED
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

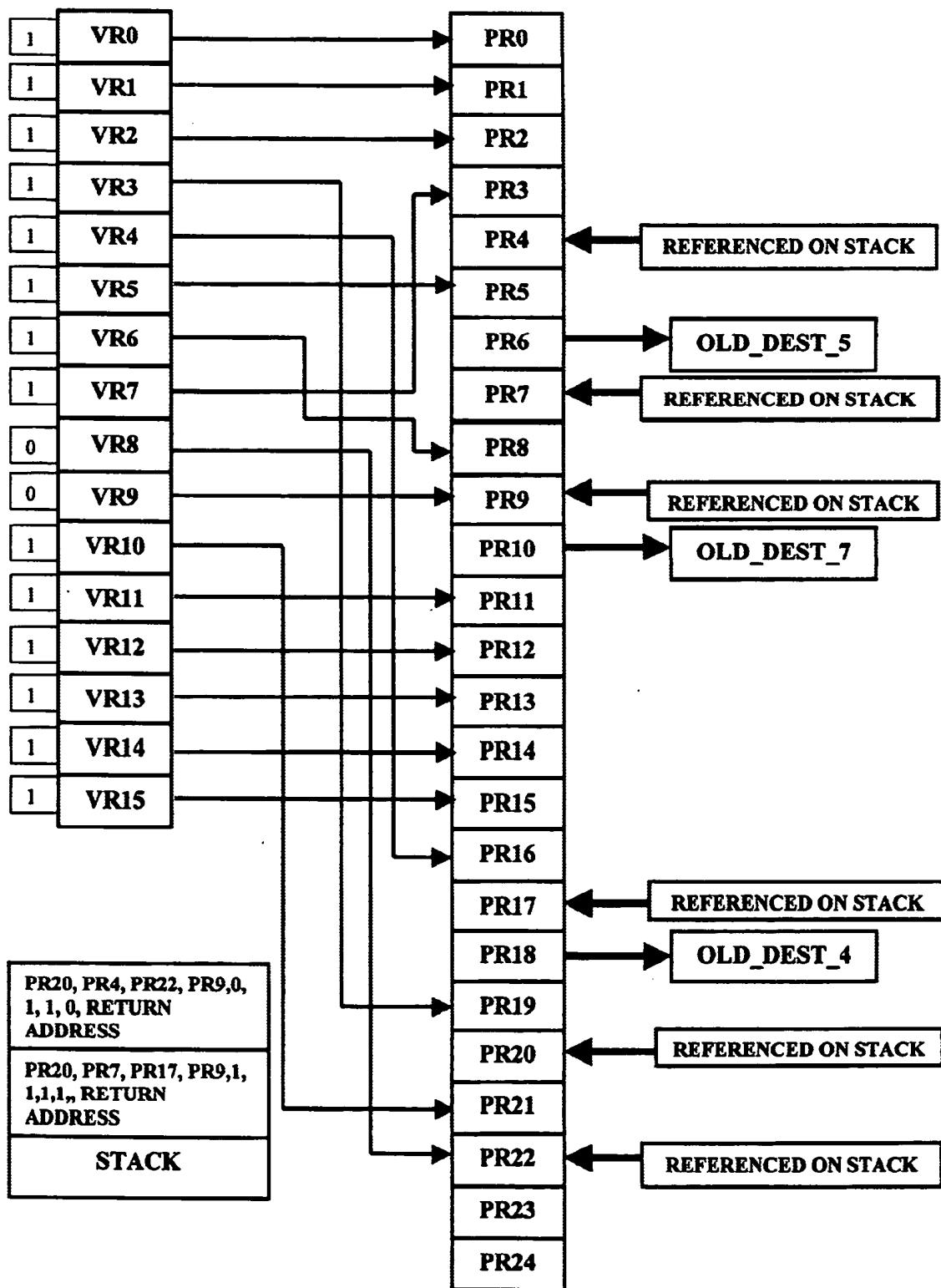
**CLOCK 6: DECODE STAGE
INSTRUCTIONS 9 & 10 PHYSICAL REGISTER STATE**

FIG. 38



INSTR. 11: ADD VR1, VR2, VR6 maps to ADD PR1, PR2, PR8
 $1 \rightarrow$ DIRTY BIT FOR VR6

FIG. 39



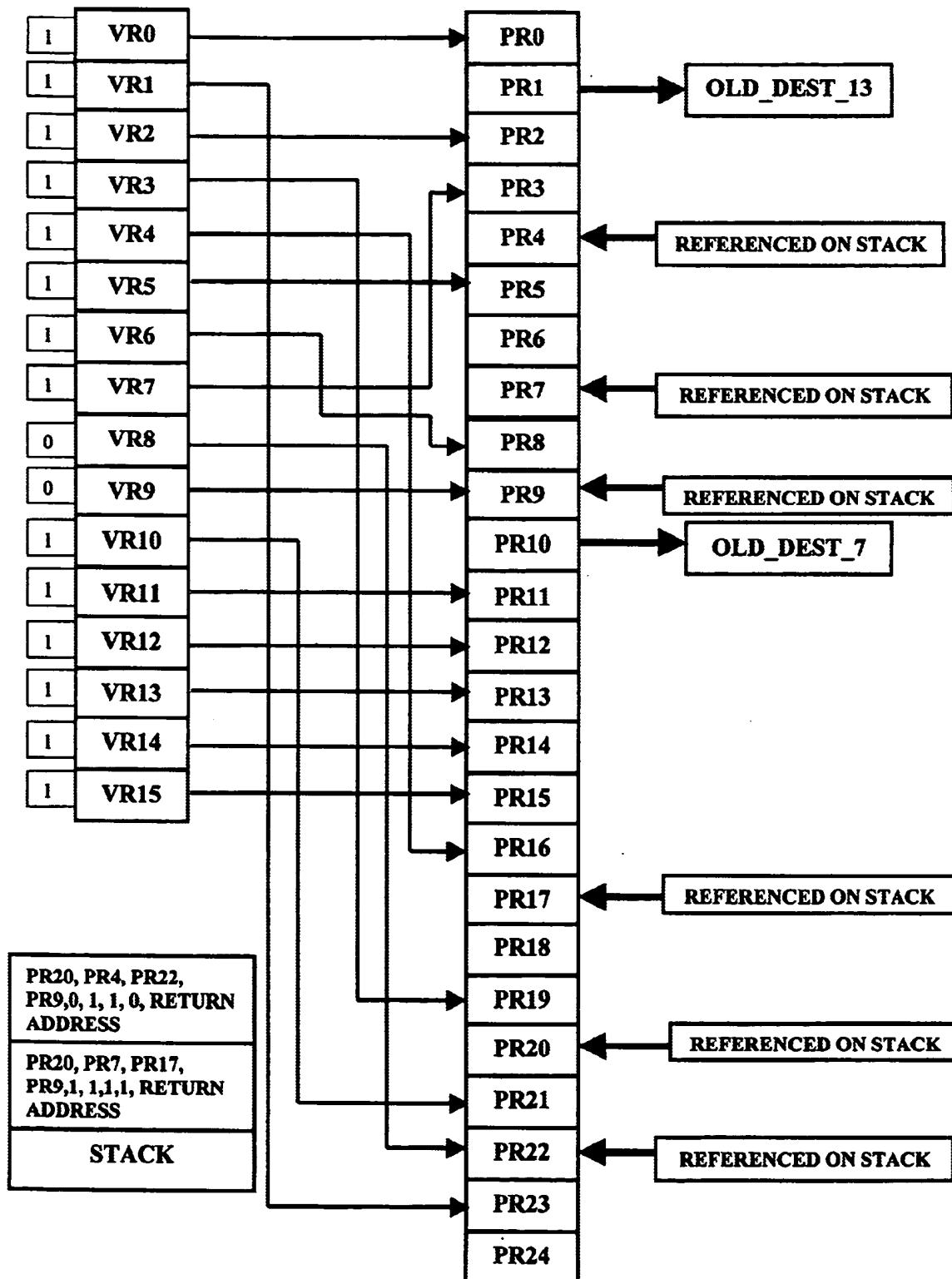
INSTR. 12: ADD VR3, VR7, VR7 maps to ADD PR19, PR4, PR3
 1 → DIRTY BIT FOR VR7

FIG. 40

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	0	-	7	WAITING FOR INSTRUCTION 12 TO EXECUTE
4	0	0	-	-	WAIT FOR INS. 9 TO EXECUTE, REF. SAVED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	-	REFERENCE PREVIOUSLY SAVED ON STACK
8	0	0	-	6	WAITING FOR INSTRUCTION 11 TO EXECUTE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INSTRUCTION 2 EXECUTED
18	0	1	2	-	WAITING FOR INSTRUCTION 4 TO RETIRE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	-	REFERENCE PREVIOUSLY SAVED ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

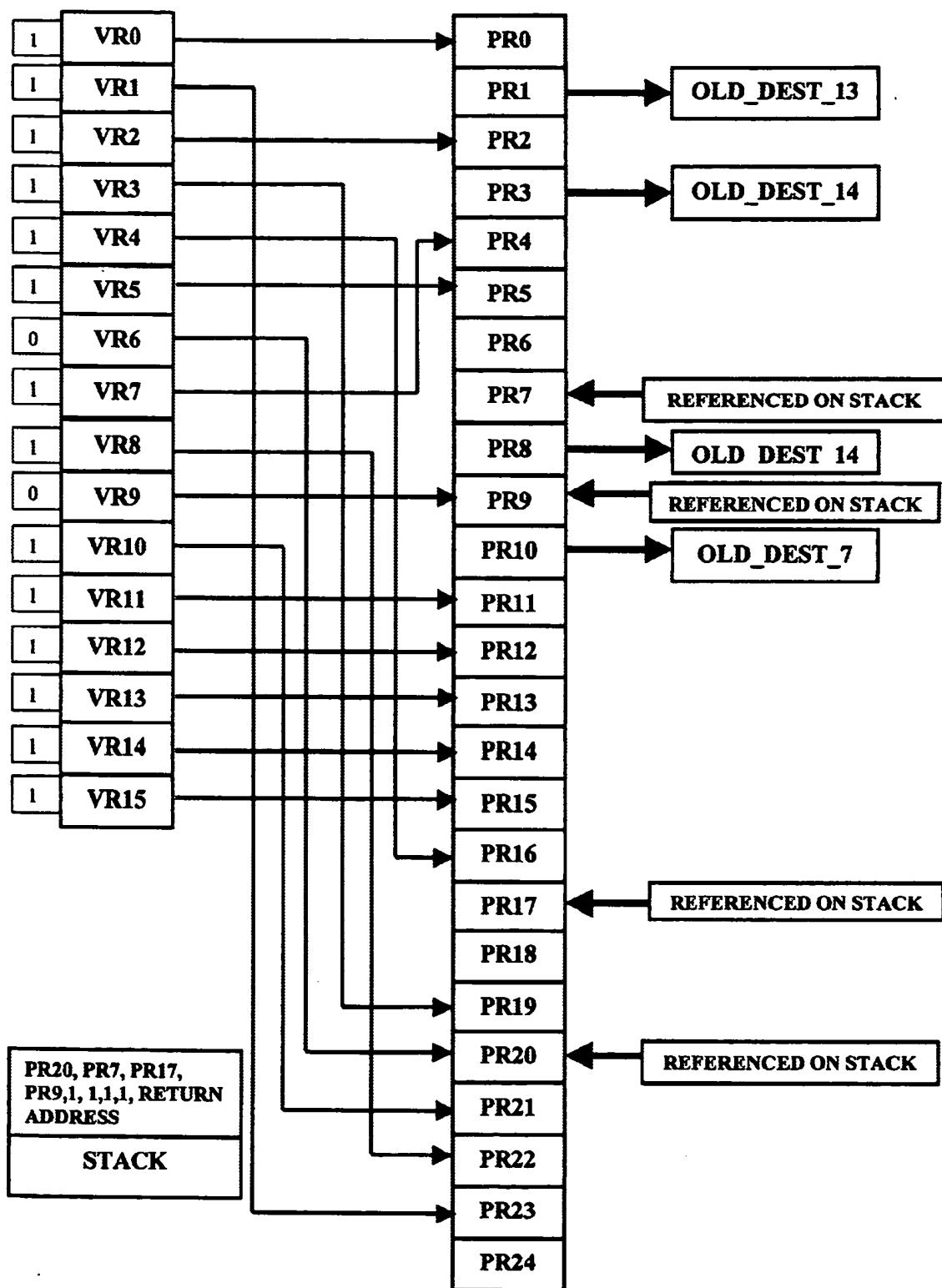
**CLOCK 7: DECODE STAGE
INSTRUCTIONS 11 & 12 PHYSICAL REGISTER STATE**

FIG. 41



INSTR. 13: MUL VR6, VR7, VR1 maps to MUL PR8, PR3, PR23
PR1 → OLD_DEST_13

FIG. 42



INSTR. 14: RET maps to
9'S DIRTY BITS,

POP PR20, PR4, PR22, PR9 → VR6-9, 0110 → VR6-

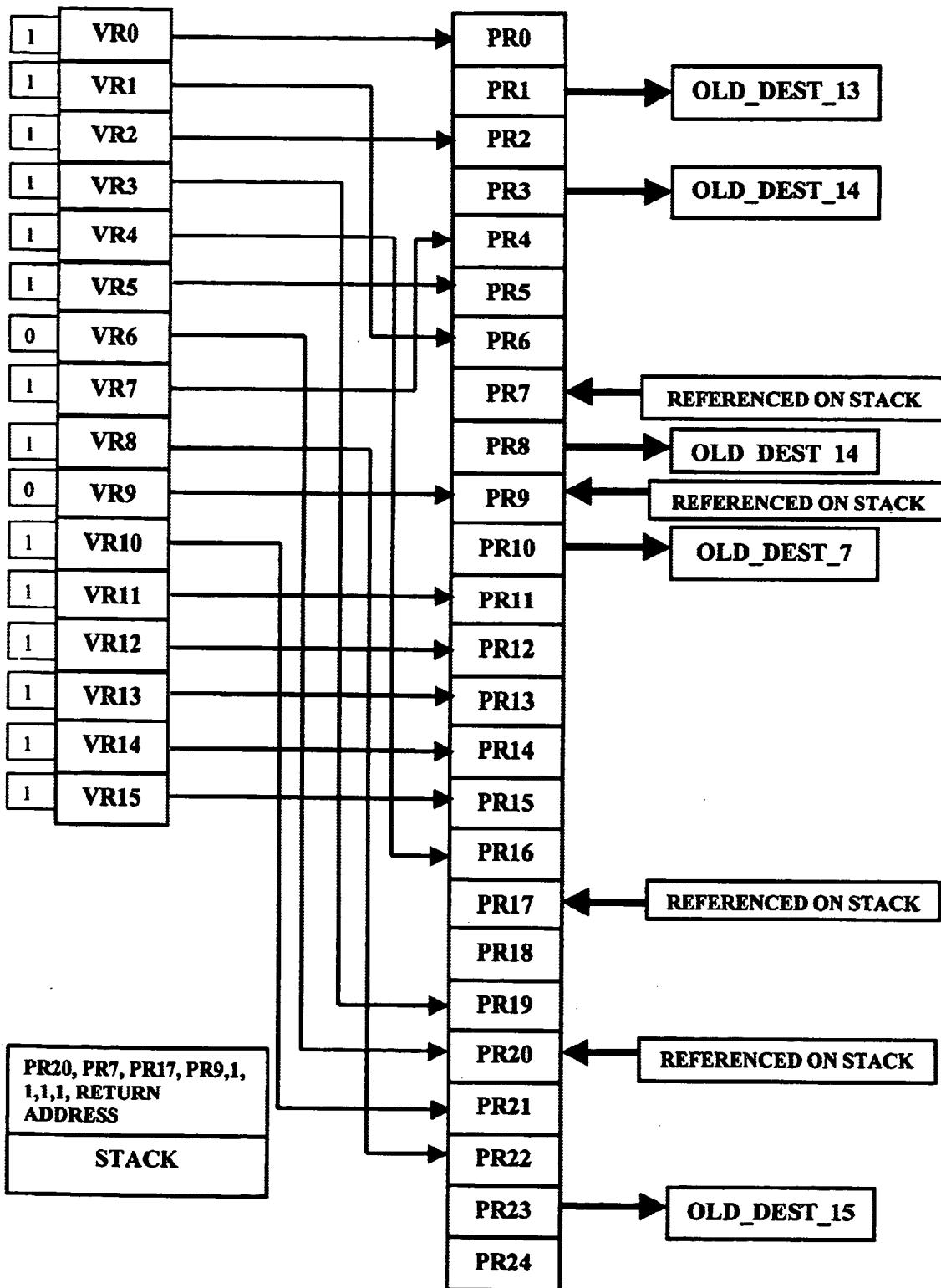
RETURN FROM SUBR. B, PR3 & PR8 → OLD_DEST_14

FIG. 43

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	0	-	7	WAIT FOR INS. 9 EXEC., VR7 REF. RESTORED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	1	-	-	-	INSTRUCTION 5 RETIRED
7	0	1	17	-	REFERENCE PREVIOUSLY SAVED ON STACK
8	0	0	-	-	WAIT FOR INS. 11 TO EXEC. & 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INSTRUCTION 2 EXECUTED
18	1	-	-	-	INSTRUCTION 4 RETIRED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	0	0	-	1	WAITING FOR INSTRUCTION 13 TO EXECUTE
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

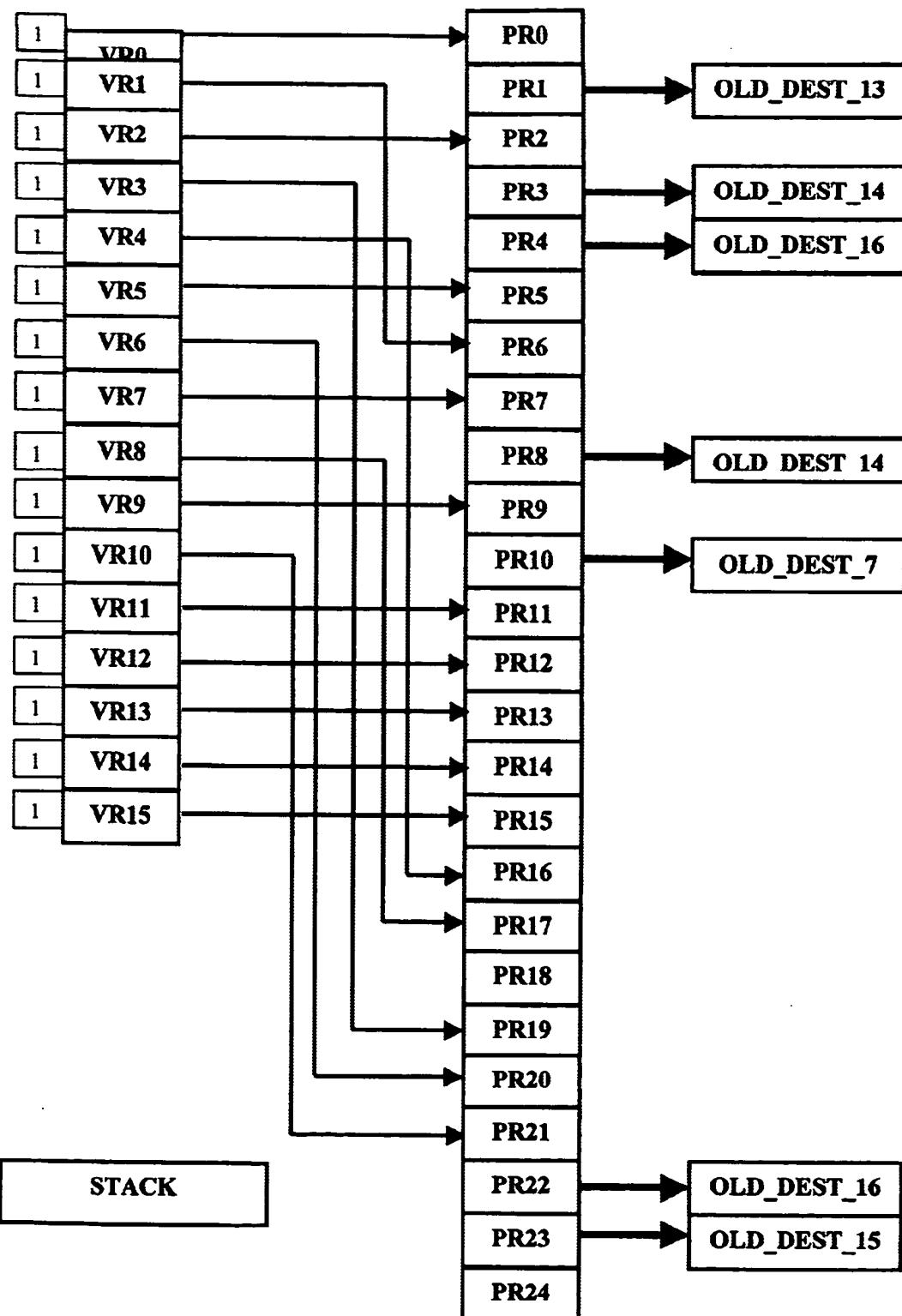
**CLOCK 8: DECODE STAGE
INSTRUCTIONS 13 & 14 PHYSICAL REGISTER STATE**

FIG. 44



INSTR. 15: ADD VR8, VR7, VR1 maps to ADD PR22, PR4, PR6
 $PR23 \rightarrow OLD_DEST_15$

FIG. 45



INSTR. 16: RET maps to POP PR20, PR7, PR17, PR9 → VR6-9, 1111 → VR6-9'S DIRTY BITS,

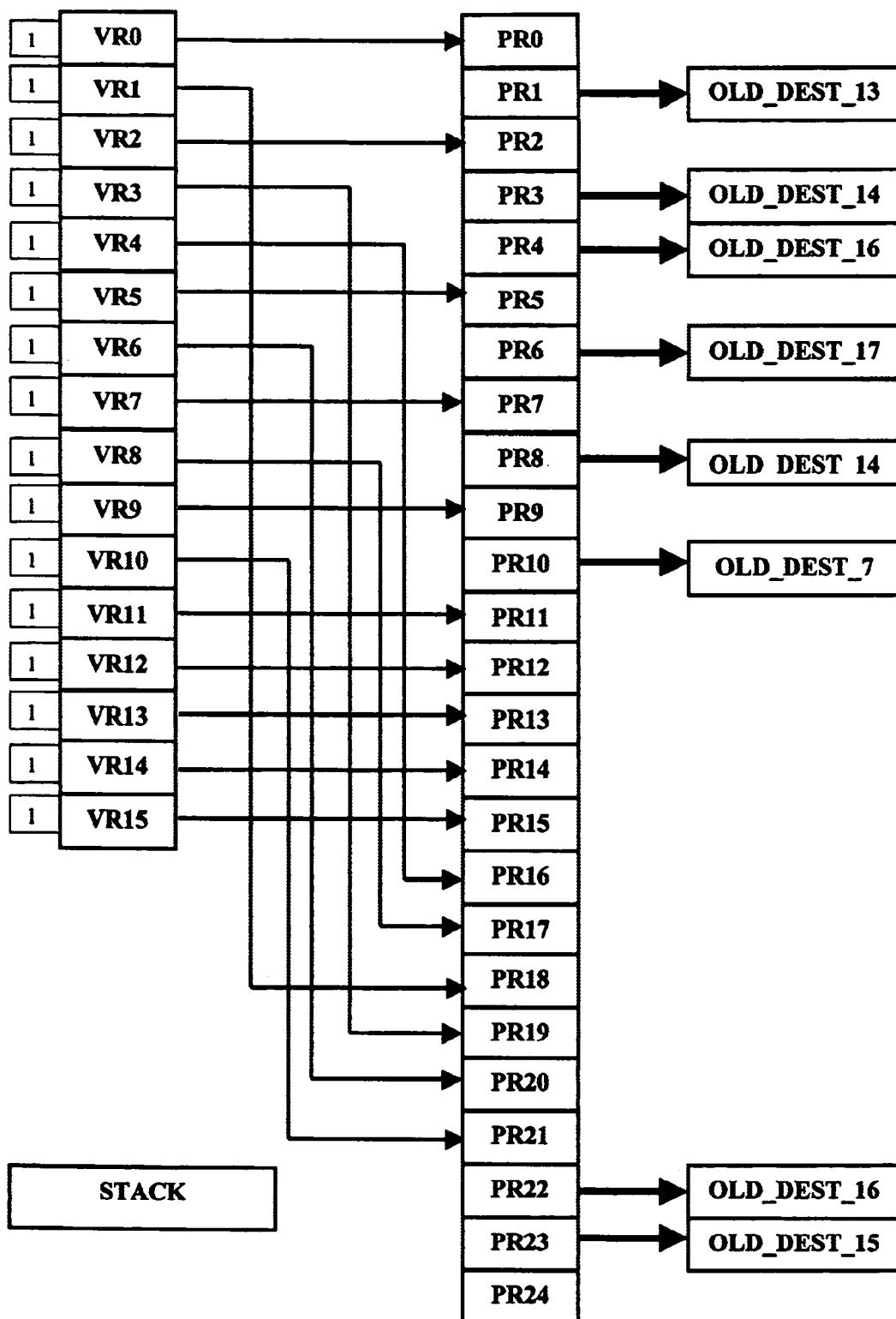
RETURN FROM SUBR. A, PR4 & PR22 → OLD_DEST_16

FIG. 46

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	0	-	-	WAIT FOR INS. 9 EXEC., INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	1	WAITING FOR INSTRUCTION 15 TO EXECUTE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	0	-	-	WAIT FOR INS. 11 TO EXEC. & 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	1	-	-	-	INSTRUCTION 4 RETIRED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

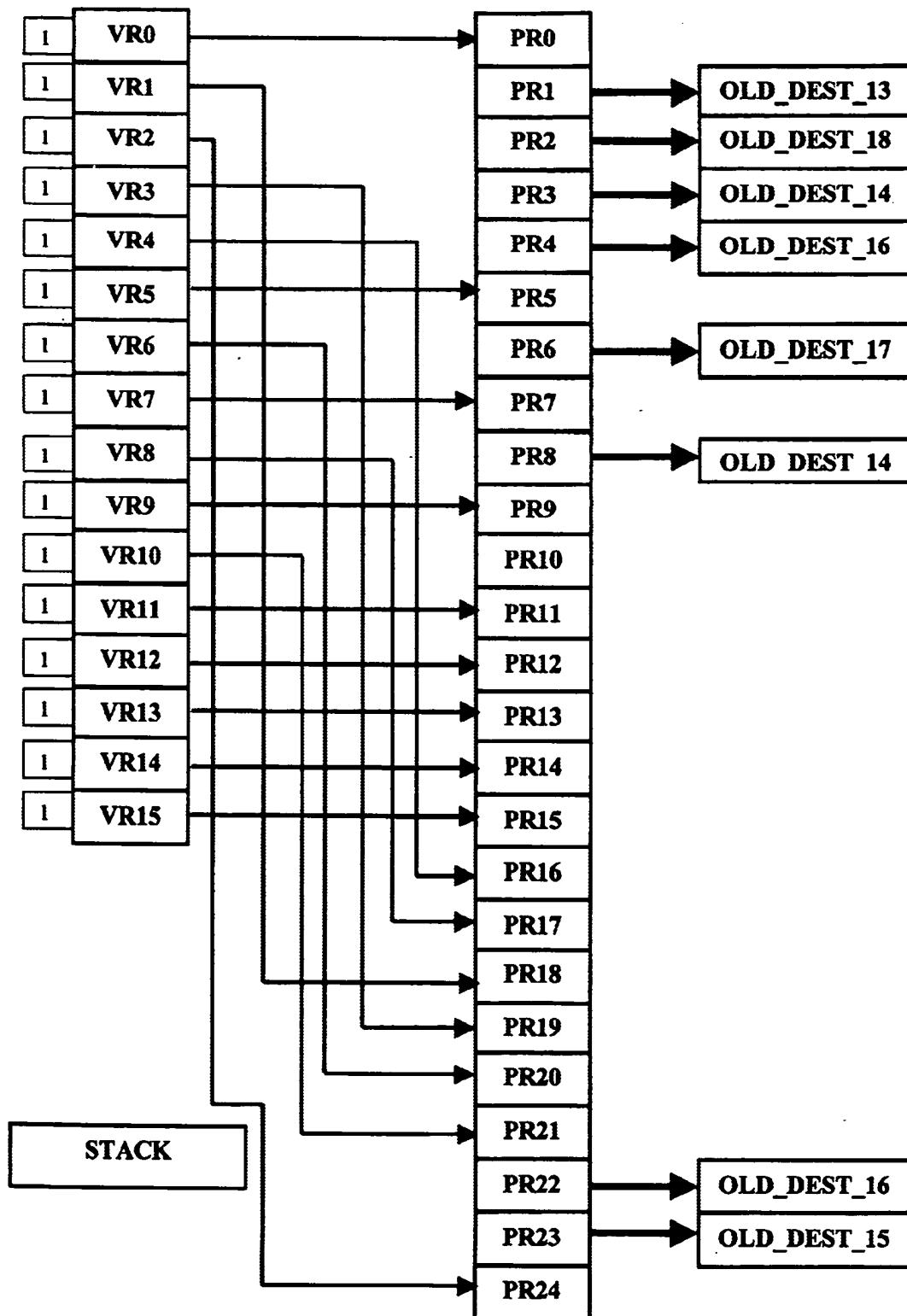
**CLOCK 9: DECODE STAGE
INSTRUCTIONS 15 & 16 PHYSICAL REGISTER STATE**

FIG. 47



INSTR. 17: ADD VR8, VR1, VR1 maps to ADD PR17, PR6, PR18
 PR6 → OLD_DEST_17

FIG. 48



INSTR. 18: ADD VR8, VR2, VR2 maps to ADD PR17, PR2, PR24
 $PR2 \rightarrow OLD_DEST_18$

FIG. 49

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	-	WAIT FOR INS. 15 TO EXEC. & 17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	0	-	1	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	0	0	-	2	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 10: DECODE STAGE
INSTRUCTIONS 17 & 18 PHYSICAL REGISTER STATE**

FIG. 50

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	-	WAIT FOR INS. 15 TO EXEC. & 17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	0	-	1	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	0	0	-	2	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

CLOCK 11: DECODE STAGE
NO CHANGE IN PHYSICAL REGISTER STATE

FIG. 51

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	1	-13	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	-30	-	WAIT FOR INS.17 TO RETIRE.
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	0	-	1	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	0	0	-	2	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 12: DECODE STAGE
PHYSICAL REGISTER STATE**

FIG. 52

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	1	-13	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	-30	-	WAIT FOR INS.17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	1	-134	1	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	-	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	0	1	-8	2	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 13: DECODE STAGE
PHYSICAL REGISTER STATE**

FIG. 53

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	1	-13	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	-30	-	WAIT FOR INS.17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	1	-134	1	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	1	-156	-	WAIT FOR INS. 15 TO RETIRE
24	0	1	-8	2	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 14: DECODE STAGE
PHYSICAL REGISTER STATE**

FIG. 54

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	1	-	-	-	INSTRUCTION 13 RETIRED
2	1	-	-	-	INSTRUCTION 18 RETIRED
3	1	-	-	-	INSTRUCTION 14 RETIRED
4	1	-	-	-	INSTRUCTION 16 RETIRED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	1	-	-	-	INSTRUCTION 17 RETIRED
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	1	-	-	-	INSTRUCTION 14 RETIRED
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	1	-134	1	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	1	-	-	-	INSTRUCTION 16 RETIRED
23	1	0	-	-	INSTRUCTION 15 RETIRED
24	0	1	-8	2	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 15: DECODE STAGE
PHYSICAL REGISTER STATE**

FIG. 55

```

A: ADD VR6, VR3, VR10    Subroutine uses Arguments VR1 and VR2
   SUB VR2, VR3, VR8
   MUL VR8, VR1, VR7
   CALL B, 2, 8           ; Bind Arg2 to new Arg1 and bind VR8 to new Arg2
   ADD VR8, VR7, VR1
   RET                   ; Restore previous argument bindings

B: ADD VR1, VR2, VR6    Subroutine uses Arguments VR1 and VR2
   ADD VR3, VR7, VR7
   MUL VR6, VR7, VR1
   RET                   ; Restore previous argument bindings

start of example execution

C:   □
     □
     □
     ADD VR0, VR0, VR4
     LIM VR8, #22
     SUB VR3, VR0, VR3
     ADD VR4, VR3, VR3
     MUL VR4, VR5, VR6
     CALL A, 6, 8          ; Bind VR6 to new Arg1 and bind VR8 to new Arg2
     ADD VR8, VR0, VR0
     ADD VR8, VR6, VR6
     □
     □
     □

```

end of example execution

EXAMPLE PROGRAM

FIG. 56

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	DESCRIPTION
0	0	1	3	EXAMPLE INITIALIZATION
1	0	1	5	EXAMPLE INITIALIZATION
2	0	1	7	EXAMPLE INITIALIZATION
3	0	1	9	EXAMPLE INITIALIZATION
4	0	1	11	EXAMPLE INITIALIZATION
5	0	1	13	EXAMPLE INITIALIZATION
6	0	1	15	EXAMPLE INITIALIZATION
7	0	1	17	EXAMPLE INITIALIZATION
8	0	1	19	EXAMPLE INITIALIZATION
9	0	1	21	EXAMPLE INITIALIZATION
10	0	1	23	EXAMPLE INITIALIZATION
11	0	1	25	EXAMPLE INITIALIZATION
12	0	1	27	EXAMPLE INITIALIZATION
13	0	1	29	EXAMPLE INITIALIZATION
14	0	1	31	EXAMPLE INITIALIZATION
15	0	1	33	EXAMPLE INITIALIZATION
16	1	-	-	UNALLOCATED
17	1	-	-	UNALLOCATED
18	1	-	-	UNALLOCATED
19	1	-	-	UNALLOCATED
20	1	-	-	UNALLOCATED
21	1	-	-	UNALLOCATED
22	1	-	-	UNALLOCATED
23	1	-	-	UNALLOCATED
24	1	-	-	UNALLOCATED
ETC.	1	-	-	UNALLOCATED

**CLOCK 1: DECODE STAGE
INITIAL PHYSICAL REGISTER STATE**

FIG. 57

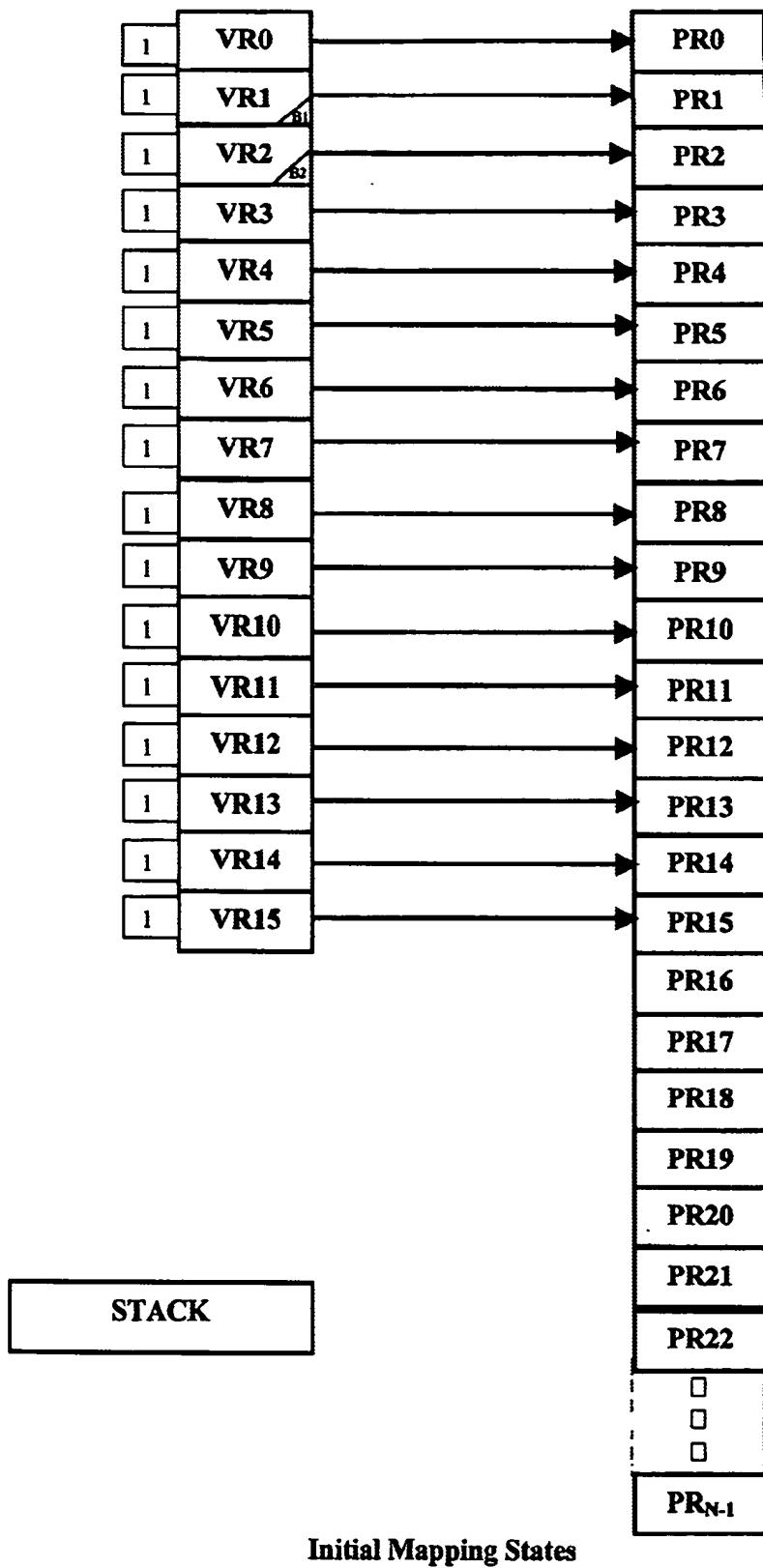


FIG. 58

INSTRUCTION #	INSTRUCTION	DESCRIPTION	EFFECT OF INSTRUCTION
1	ADD VR0, VR0, VR4	VR0 + VR0 → VR4	(3 + 3) → 6 → VR4
2	LIM VR8, #22	22 → VR8	22 ₁₀ → VR8
3	SUB VR3, VR0, VR3	VR3 - VR0 → VR3	(9 - 3) → 6 → VR3
4	ADD VR4, VR3, VR3	VR4 + VR3 → VR3	(6 + 6) → 12 → VR3
5	MUL VR4, VR5, VR6	VR4 * VR5 → VR6	(6 * 13) → 78 → VR6
6	CALL A, VR6, VR8	CALL subroutine A(Arg1, Arg2)	Arg1 □ VR6, Arg2 □ VR8, VR6 → VR9 scratch registers; VR1 □ Arg1, VR2 □ Arg2.
7	ADD VR1, VR3, VR10	VR1 + VR3 → VR10	((78 + 12) → 90 → VR10 (Uses C program's VR6 as source))
8	SUB VR2, VR3, VR8	VR2 - VR3 → VR8	((22 - 12) → 10 → VR8 (Uses C program's VR8 as source))
9	MUL VR8, VR1, VR7	VR8 * VR1 → VR7	((10 * 78) → 780 → VR7 (use VR7 as scratch register))
10	CALL B, VR2, VR8	CALL subroutine B(Arg1, Arg2)	Arg1 □ A's Arg2, Arg2 □ VR8, VR6 → VR9 scratch registers; VR1 □ Arg1, VR2 □ Arg2
11	ADD VR1, VR2, VR6	VR1 + VR2 → VR6	((22 + 10) → 32 → VR6 (Uses C program's VR8 as source, A program's VR8 as source, and uses VR6 as scratch register))
12	ADD VR3, VR7, VR7	VR3 + VR7 → VR7	((12 + 780) → 792 → VR7 (use VR7 as scratch register))
13	MUL VR6, VR7, VR1	VR6 * VR7 → VR1	((32 * 792) → 25344 → VR1 (Uses C program's VR8 as destination))
14	RET	RETURN	restore value of 78 to VR6, 780 to VR7, VR1 link to C's VR6, and VR2 link to C's VR8.
15	ADD VR8, VR7, VR1	VR8 + VR7 → VR1	((10 + 780) → 790 → VR1 (Uses C program's VR6 as destination))
16	RET	RETURN	restore value of 790 to VR6, 17 to VR7, 25344 to VR8, and VR1 and VR2 links to VRs in Program that Called C.
17	ADD VR8, VR0, VR0	VR8 + VR0 → VR0	((25344 + 3) → 25347 → VR0)
18	ADD VR8, VR6, VR6	VR8 + VR6 → VR6	((25344 + 790) → 26134 → VR6)

EXAMPLE INSTRUCTION FLOW

FIG. 59

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INSTRUCTION NUMBER	VIRTUAL REGISTER NUMBER:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
INSTRUCTION NUMBER	INITIAL VALUE:	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
1	ADD VR0, VR0, VR4	3	5	7	9	6	13	15	17	19	21	23	25	27	29	31
2	LIM VR8, #22	3	5	7	9	6	13	15	17	22	21	23	25	27	29	31
3	SUB VR3, VR0, VR3	3	5	7	6	6	13	15	17	22	21	23	25	27	29	31
4	ADD VR4, VR3, VR3	3	5	7	12	6	13	15	17	22	21	23	25	27	29	31
5	MUL VR4, VR5, VR6	3	5	7	12	6	13	78	17	22	21	23	25	27	29	31
6	CALL A, VR6, VR8	3	78	22	12	6	13	78	17	22	21	23	25	27	29	31
7	ADD VR1, VR3, VR10	3	78	22	12	6	13	78	17	22	21	90	25	27	29	31
8	SUB VR2, VR3, VR8	3	78	22	12	6	13	78	17	10	21	90	25	27	29	31
9	MUL VR8, VR1, VR7	3	78	22	12	6	13	78	780	10	21	90	25	27	29	31
10	CALL B, VR2, VR8	3	22	10	12	6	13	78	780	10	21	90	25	27	29	31
11	ADD VR1, VR2, VR6	3	22	10	12	6	13	32	780	10	21	90	25	27	29	31
12	ADD VR3, VR7, VR7	3	22	10	12	6	13	32	792	10	21	90	25	27	29	31
13	MUL VR6, VR7, VR1	3	25344	10	12	6	13	32	792	10	21	90	25	27	29	31
14	RET	3	78	22	12	6	13	78	780	10	21	90	25	27	29	31
15	ADD VR8, VR7, VR1	3	790	22	12	6	13	78	780	10	21	90	25	27	29	31
16	RET	3	5	7	12	6	13	790	17	25344	21	90	25	27	29	31
17	ADD VR8, VR0, VR0	25347	5	7	12	6	13	790	17	25344	21	90	25	27	29	31
18	ADD VR8, VR6, VR6	25347	5	7	12	6	13	26134	17	25344	21	90	25	27	29	31

CONTENTS OF VIRTUAL REGISTERS AS INSTRUCTIONS EXECUTE

FIG. 60

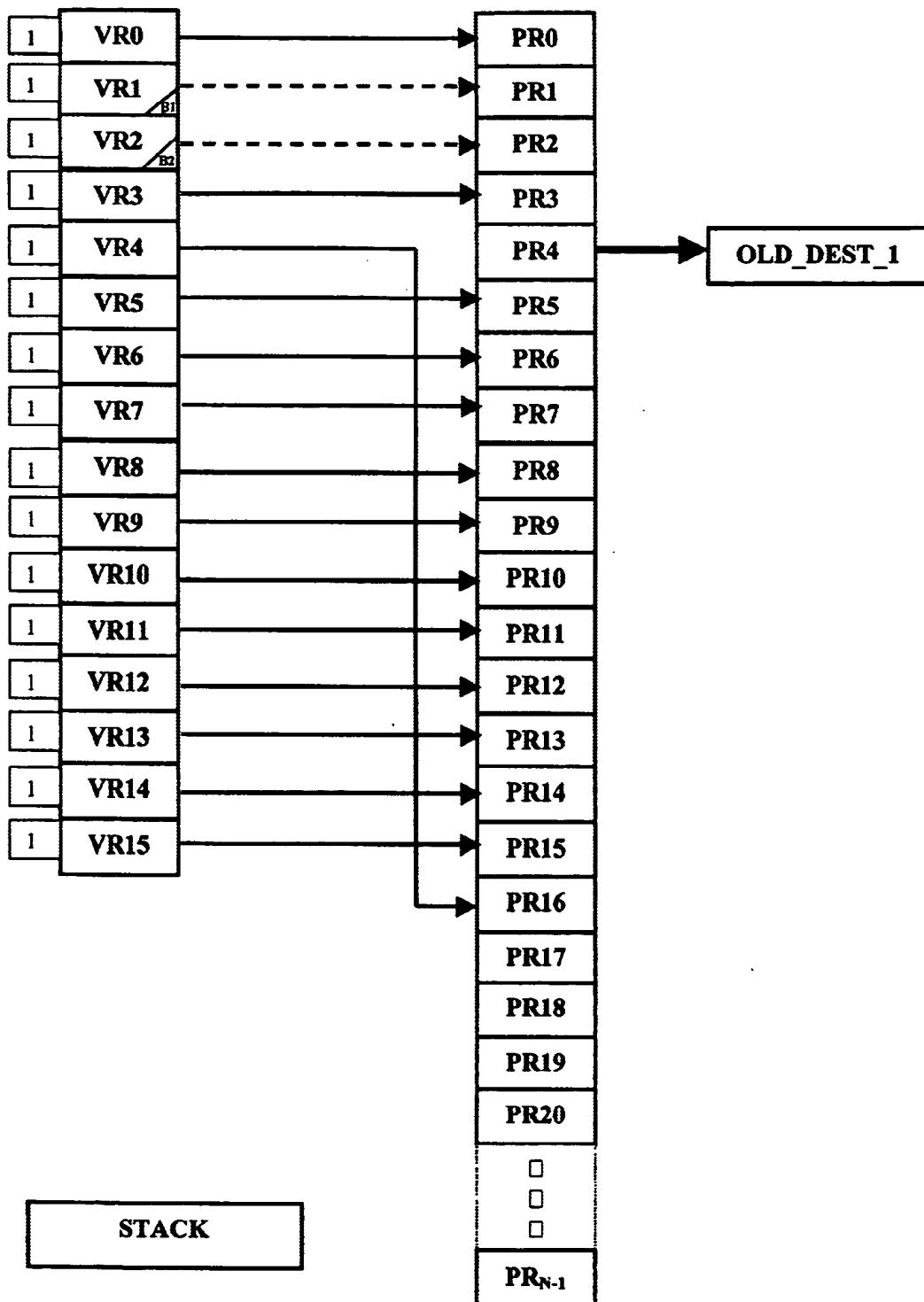
<u>Clock 1</u>	Fetch instr. 1, 2;			
<u>Clock 2</u>	Fetch instr. 3, 4;	Decode instr. 1, 2;		
<u>Clock 3</u>	Fetch instr. 5, 6;	Decode instr. 3, 4;	Read regs. PR0 for instr. 1.	
<u>Clock 4</u>	Fetch instr. 7, 8;	Decode instr. 5, 6;	Read regs. PR0, PR3 for instr. 3;	Execute instr. 1, 2 and store results in PR16, PR17 respectively. Execute instr. 6 (CALL A) including binding VR1 to VR6 and VR2 to VR8.
<u>Clock 5</u>	Fetch instr. 9, 10;	Decode instr. 7, 8;	Read regs. PR5, PR16 for instr. 5;	Execute instr. 3; store result in PR18. Retire instr. 1, 2.
<u>Clock 6</u>	Fetch instr. 11, 12;	Decode instr. 9, 10;	Read regs. PR16, PR18 for instr. 4;	Execute instr. 5 and store result in PR20; Execute instr. 10 (CALL B) including binding VR1 to VR2 and VR2 to VR8. Retire instr. 3.
<u>Clock 7</u>	Fetch instr. 13, 14;	Decode instr. 11, 12;		Execute instr. 4 and store result in PR19.
<u>Clock 8</u>	Fetch instr. 15, 16;	Decode instr. 13, 14;	Read regs. PR17, PR19, PR20 for instr. 7, 8;	Execute instr. 14(Return) including restoring bindings to that for "A". Retire instr. 4, 5, 6.

Clock by Clock Pipeline Description**FIG. 61A**

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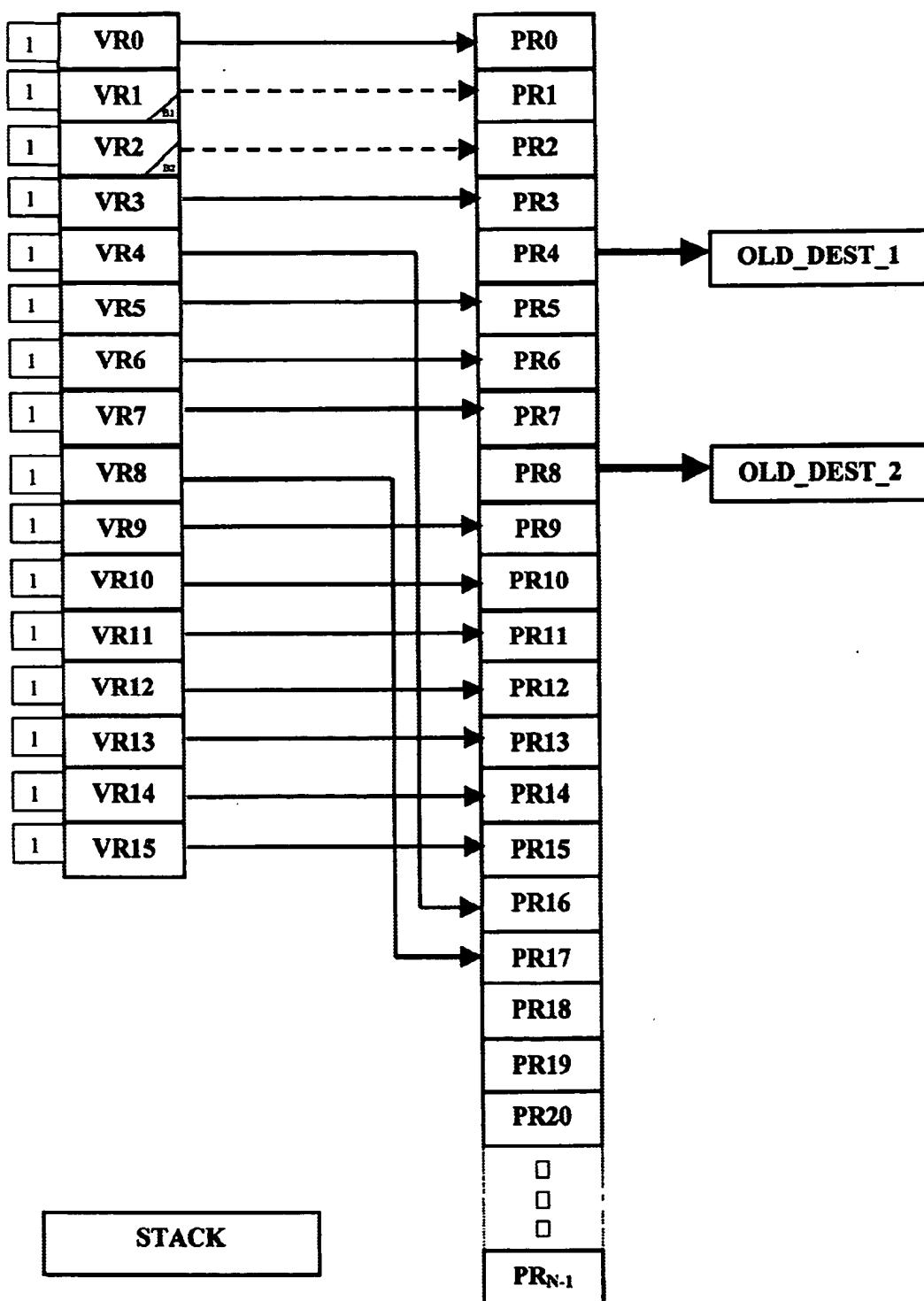
<u>Clock 9</u>	Fetch instr. 17, 18;	Decode instr. 15, 16;	Read regs. PR17, PR20, PR22 for instr. 9 and 11;	Execute instr. 7 and 8 and store results in PR21 and PR22 respectively. Execute instr. 16(Return) including restoring bindings to that for the "C".
<u>Clock 10</u>		Decode instr. 17, 18;		Execute instr. 9 and 11 and store results in PR4 and PR8 respectively.
<u>Clock 11</u>			Read regs. PR4, PR19, PR22 for instr. 12 and 15;	Retire instr. 9, 10, 11.
<u>Clock 12</u>			Read regs. PR0, PR6, PR23 for instr. 17 and 18;	Execute instr. 12, 15 and store results in PR3 and PR6 respectively.
<u>Clock 13</u>			Read regs. PR3, PR8 for instr. 13;	Execute instr. 17, 18 and store results in PR18 and PR24 respectively; Retire instr. 12.
<u>Clock 14</u>				Execute instr. 13 and store results in PR23.
<u>Clock 15</u>				Retire instr. 13, 14, 15, 16, 17, 18.

Clock by Clock Pipeline Description**FIG. 61B**



INSTR. 1: ADD VR0, VR0, VR4 maps to PR0 + PR0 → PR16,
PR4 → OLD_DEST_1

FIG. 62



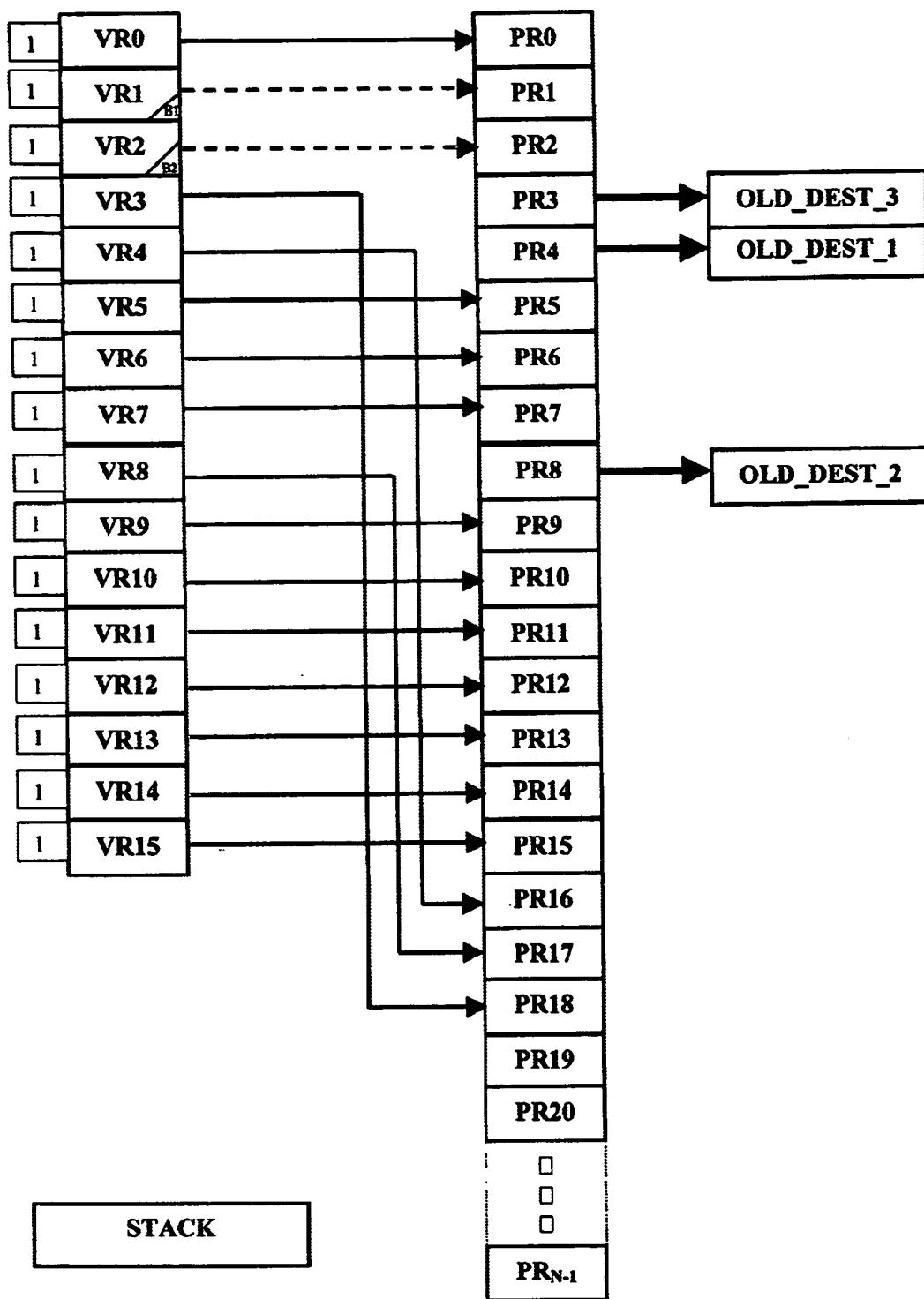
INSTR. 2: LIM VR8, #22 maps to LIM PR17, #22,
 $PR8 \rightarrow OLD_DEST_2$

FIG. 63

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	9	3	EXAMPLE INITIALIZATION
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	6	EXAMPLE INITIALIZATION
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	0	-	4	WAITING FOR INSTRUCTION 1 TO EXECUTE
17	0	0	-	8	WAITING FOR INSTRUCTION 2 TO EXECUTE
18	1	-	-	-	UNALLOCATED
19	1	-	-	-	UNALLOCATED
20	1	-	-	-	UNALLOCATED
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

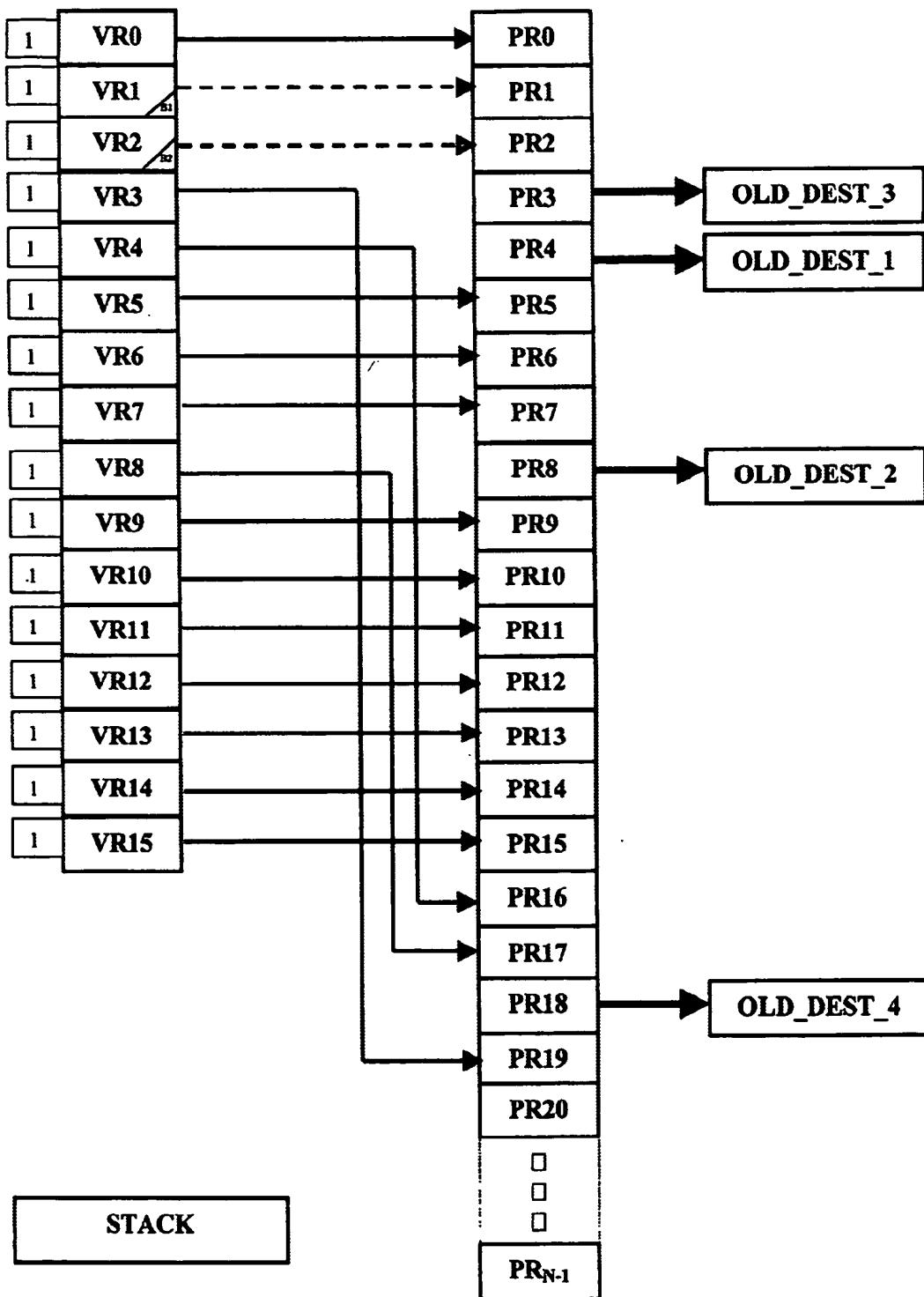
**CLOCK 2: DECODE STAGE
INSTRUCTIONS 1 & 2 PHYSICAL REGISTER STATE**

FIG. 64



INSTR. 3: SUB VR3, VR0, VR3 maps to SUB PR3, PR0, PR18,
 $PR3 \rightarrow OLD_DEST_3$

FIG. 65



INSTR. 4:

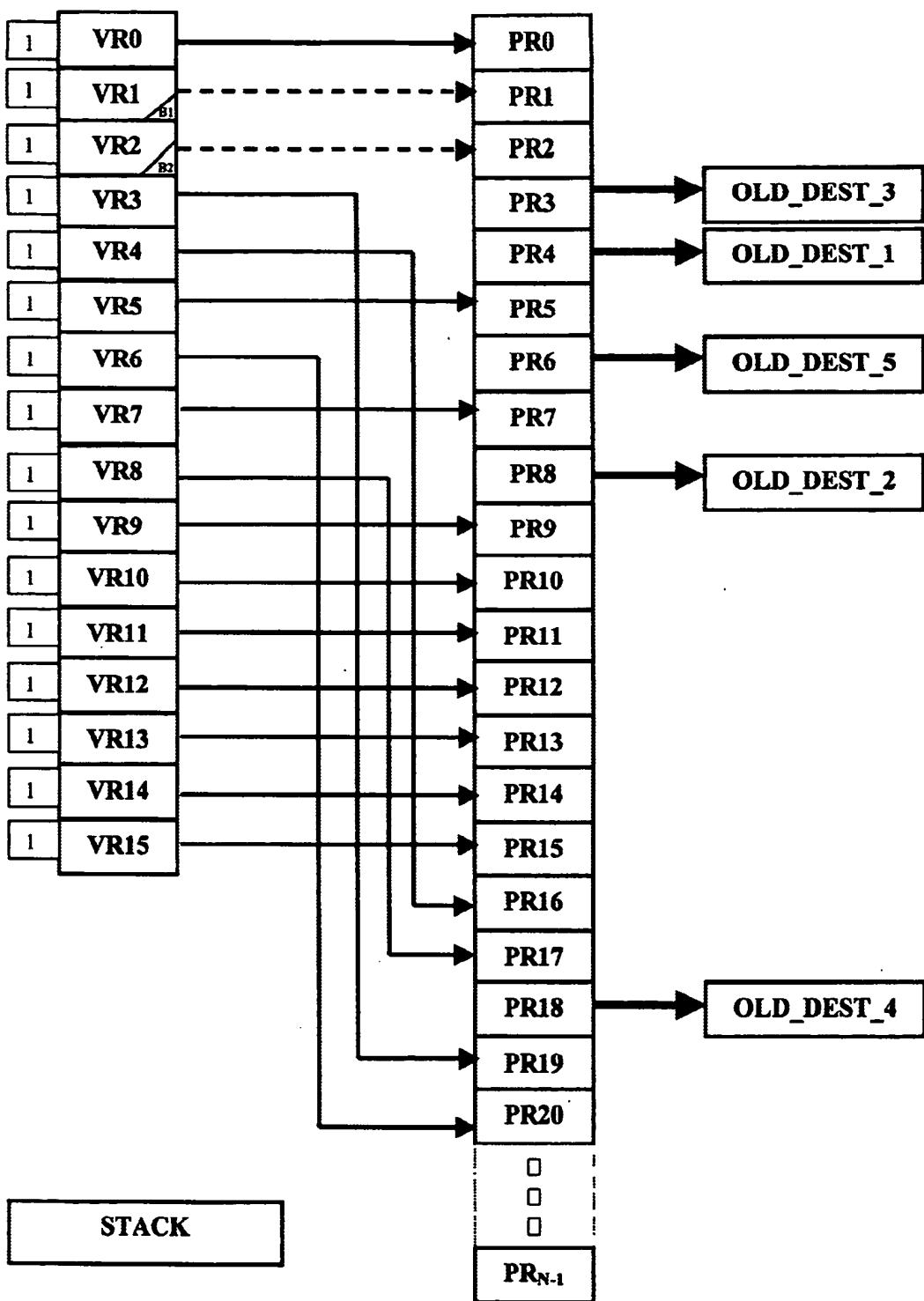
ADD VR4, VR3, VR3
PR19,maps to ADD PR16, PR18,
PR18 → OLD_DEST_4

FIG. 66

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	6	EXAMPLE INITIALIZATION
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	0	-	4	WAITING FOR INSTRUCTION 1 TO EXECUTE
17	0	0	-	8	WAITING FOR INSTRUCTION 2 TO EXECUTE
18	1	-	-	-	WAITNG FOR 3 TO EXECUTE & RETIRE
19	1	-	-	3	WAITNG FOR INSTRUCTION 4 TO EXECUTE
20	1	-	-	-	UNALLOCATED
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

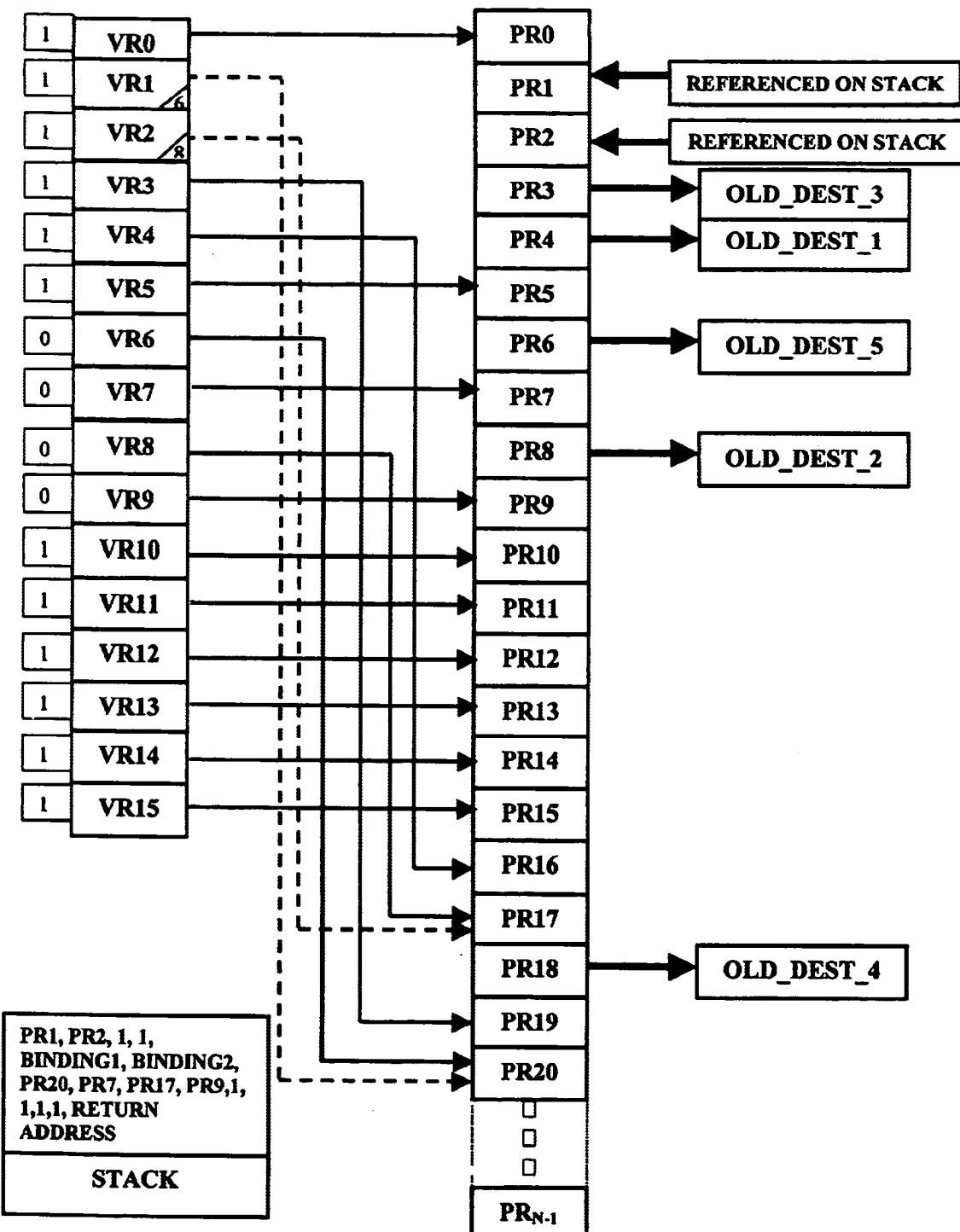
**CLOCK 3: DECODE STAGE
INSTRUCTIONS 3 & 4 PHYSICAL REGISTER STATE**

FIG. 67



INSTR. 5: MUL VR4, VRS, VR6 maps to MUL PR16, PR5, PR20,
 $PR6 \rightarrow OLD_DEST_5$

FIG. 68



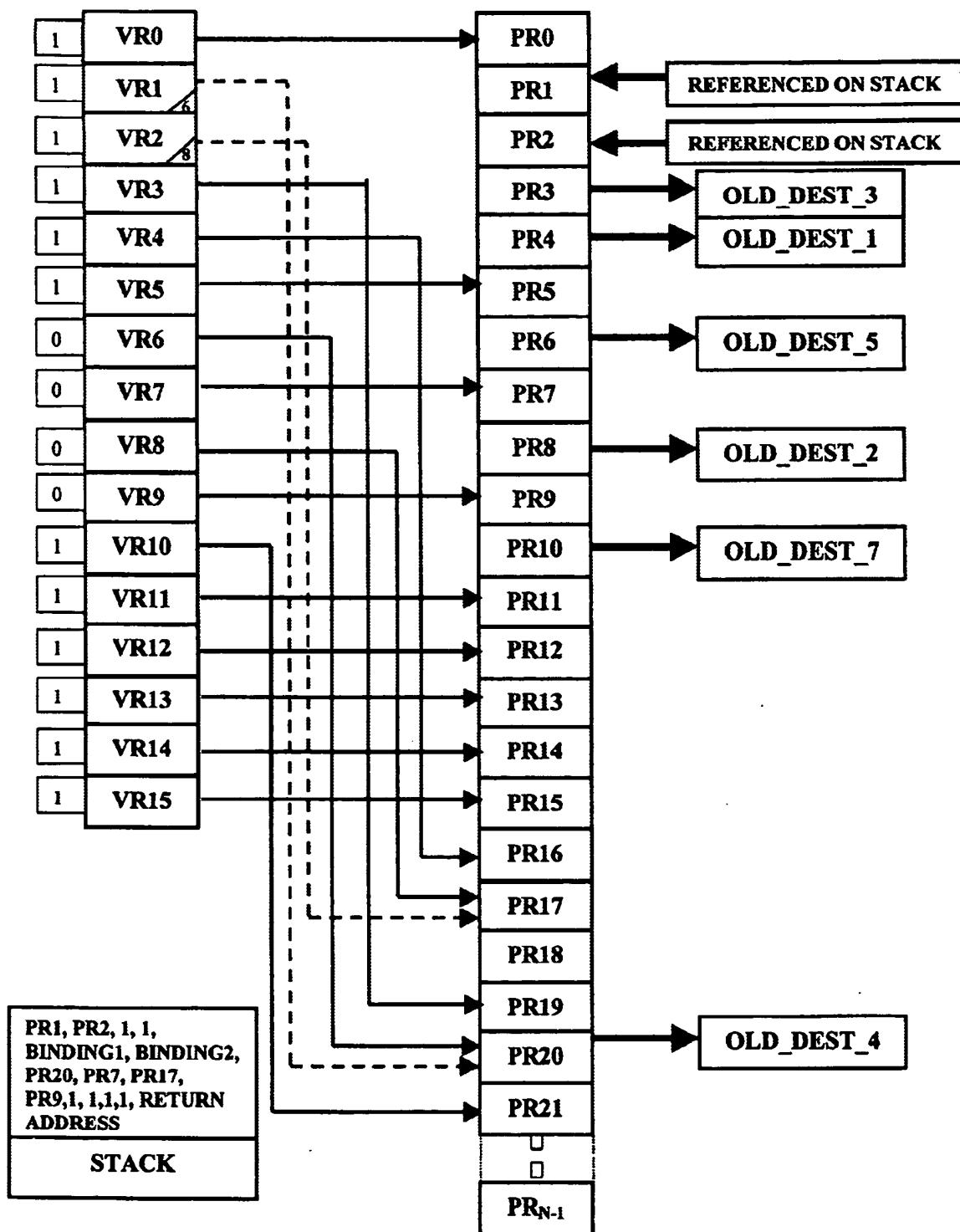
INSTR. 6: CALL A,VR6,VR8 action PUSH PR1, PR2, 1, 1,
 BINDING1, BINDING2, PR20, PR7, PR17, PR9, 1, 1, 1, 1, RETURN
 ADDRESS; BINDVR6_PR20, BINDVR8_PR17, DIRTY BITS
 FOR VR6&8 → DIRTY BITS FOR VR1&2, 0000 → DIRTY BITS
 FOR VR6-9, transfer to A

FIG. 69

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	-	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	7	REFERENCED ON STACK
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	REFERENCED ON STACK
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8, 2	INS. 2 EXECUTED, REFERENCED. ON STACK
18	0	0	-	-	WAITING FOR INST. 3 TO EXECUTE & RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	0	-	6, 1	WAIT FOR INS. 5 TO EXEC., REF'D. ON STACK
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

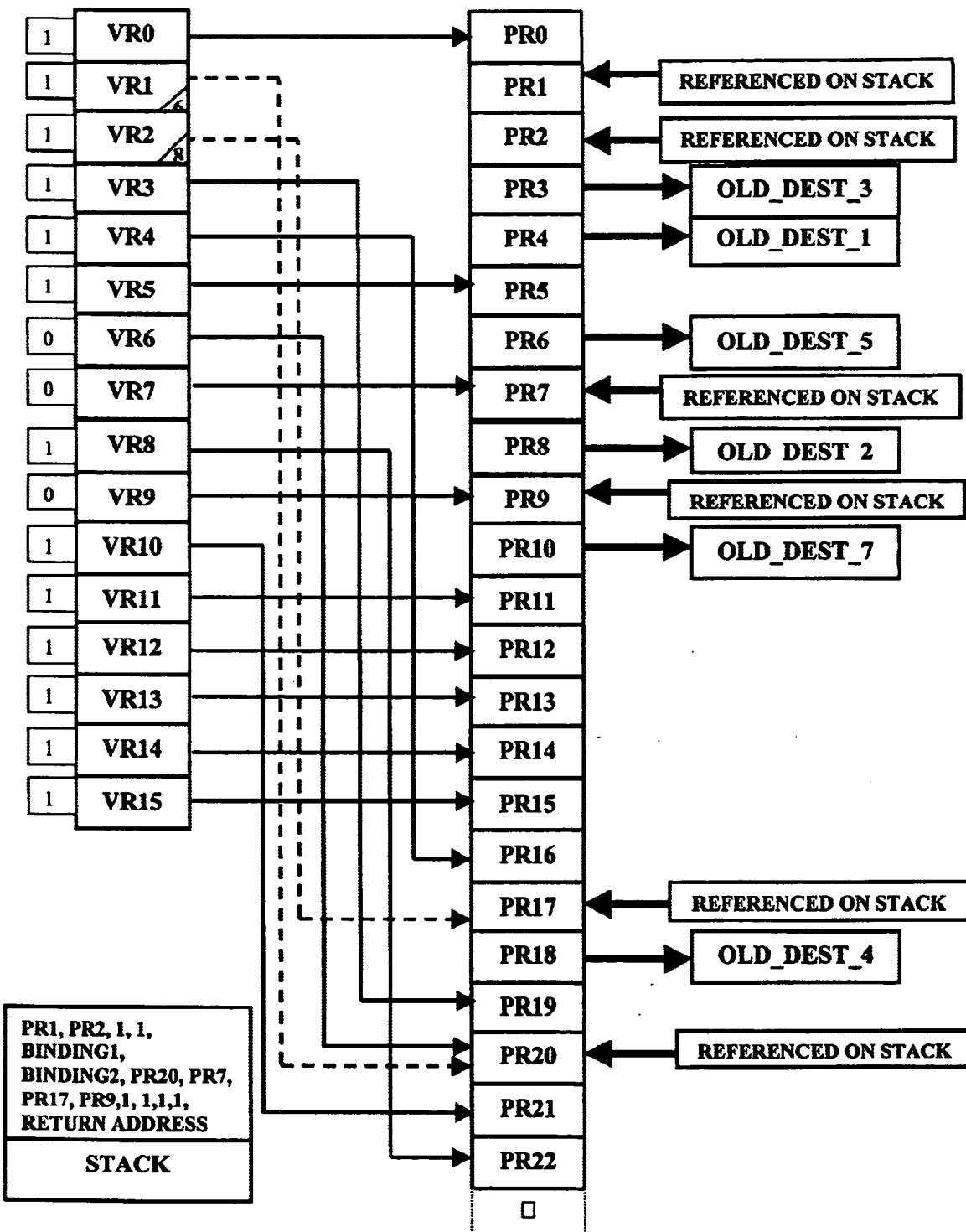
CLOCK 4: DECODE STAGE INSTRUCTIONS 5 & 6 PHYSICAL REGISTER STATE

FIG. 70



**INSTR. 7: ADD VR1, VR3, VR10 maps to ADD PR20, PR19, PR21,
PR10 → OLD_DEST_7**

FIG. 71



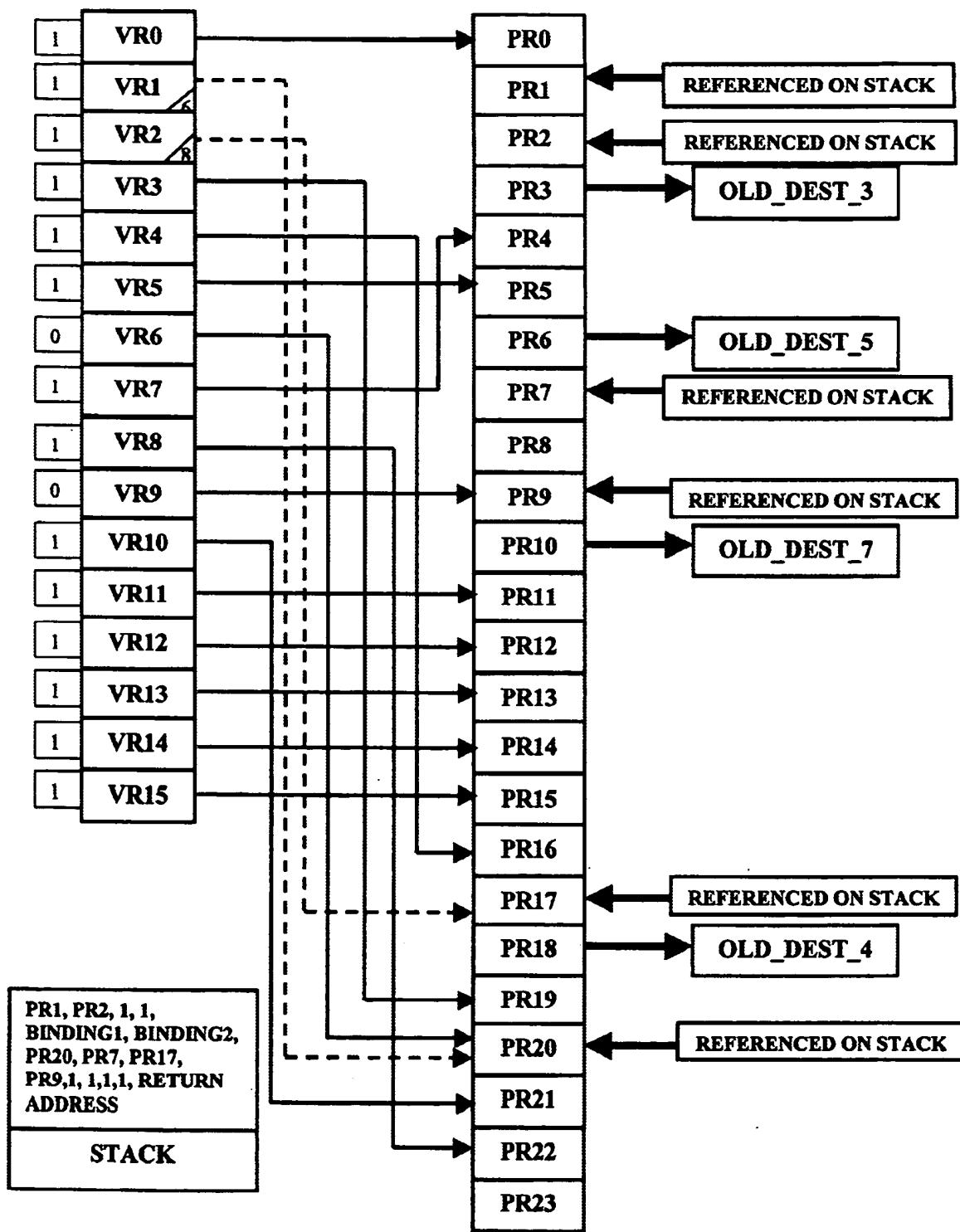
INSTR. 8: SUB VR2, VR3, VR8 maps to SUB PR17, PR19, PR22
 1 → DIRTY BIT FOR VR8

FIG. 72

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	-	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	1	-	-	-	INSTRUCTION 1 RETIRED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	7	REFERENCED ON STACK
8	1	-	-	-	INSTRUCTION 2 RETIRED
9	0	1	21	9	REFERENCED ON STACK
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED,
17	0	1	22	2	INS. 2 EXECUTED, REFERENCED ON STACK
18	0	1	6	-	INS. 3 EXECUTED WAITING FOR 4 TO RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	0	-	6, 1	WAIT FOR INS. 5 TO EXEC., REF'D. ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 5: DECODE STAGE
INSTRUCTIONS 7 & 8 PHYSICAL REGISTER STATE**

FIG. 73

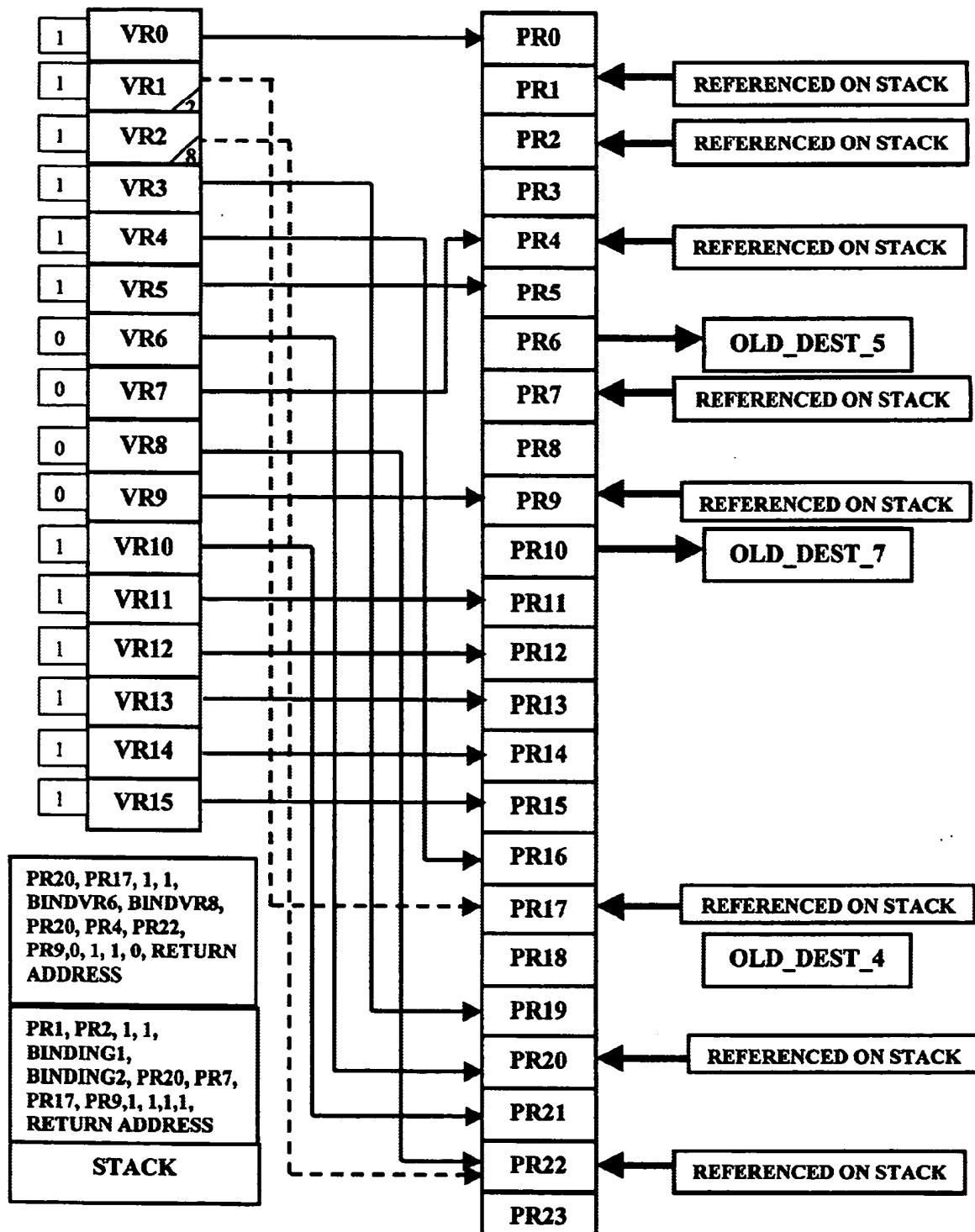


INSTR. 9: MUL VR8, VR1, VR7 maps to

MUL PR22, PR20, PR4

1 → DIRTY BIT FOR VR7

FIG. 74



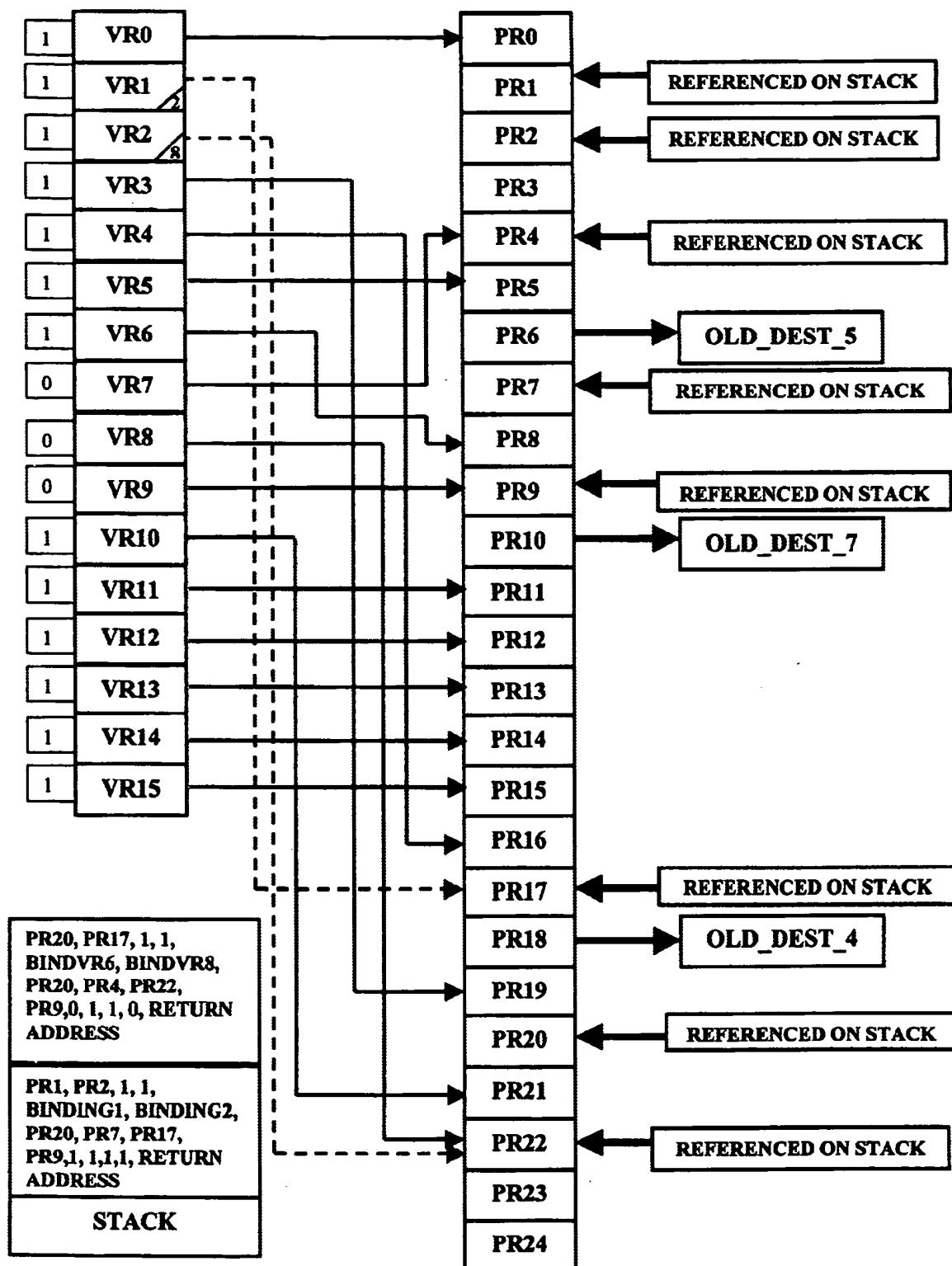
INSTR. 10: CALL B,VR2,VR8 action PUSH PR20, PR17, 1, 1, BINDVR6, BINDVR8, PR20, PR4, PR22, PR9, 0, 1, 1, 0, RETURN ADDRESS; BINDVR2_PR17, BINDVR8_PR22, DIRTY BITS FOR VR2&8 → DIRTY BITS FOR VR1&2, 0000 → DIRTY BITS FOR VR6-9, transfer to B

FIG. 75

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	-	PREVIOUSLY BOUND TO 'BINDING2'
3	1	-	-	-	INSTRUCTION 3 RETIRED
4	0	0	-	7	WAIT FOR INS. 9 TO EXEC., REF'D. ON STACK
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	-	REFERENCE PREVIOUSLY SAVED ON STACK
8	1	-	-	-	UNALLOCATED
9	0	1	21	9	REFERENCE PREVIOUSLY SAVED ON STACK
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-, 1	INS. 2 EXECUTED, REF'D. ON STACK
18	0	1	6	-	WAITING FOR INSTRUCTION 4 TO RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	1	78	6	INS. 5 EXECUTED, REF'D. ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8, 2	WAIT FOR INS. 8 TO EXEC., REF'D. ON STACK
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 6: DECODE STAGE
INSTRUCTIONS 9 & 10 PHYSICAL REGISTER STATE

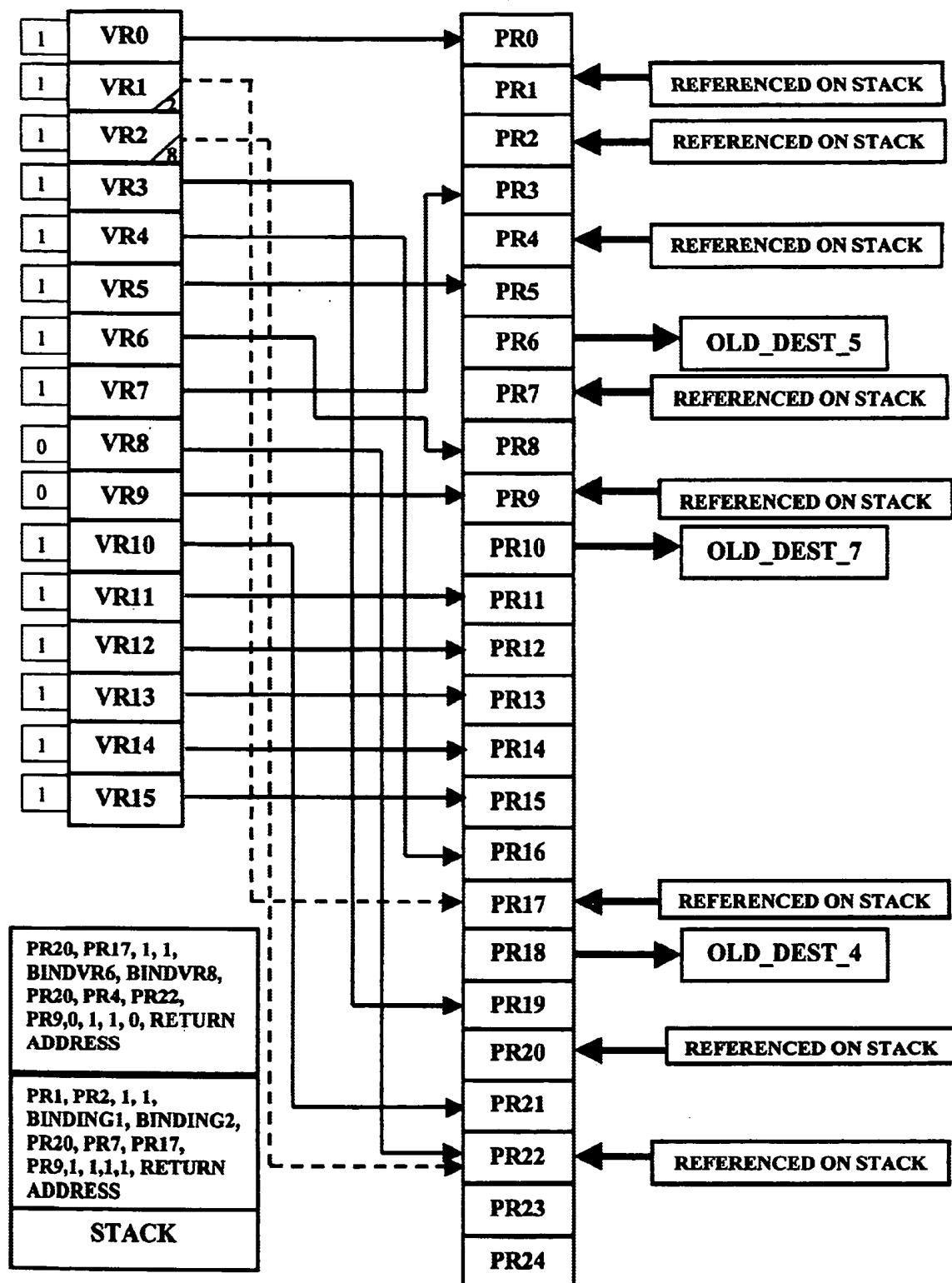
FIG. 76



INSTR. 11: ADD VR1, VR2, VR6 maps to ADD PR17, PR22, PR8
 $1 \rightarrow$ DIRTY BIT FOR VR6

FIG. 77

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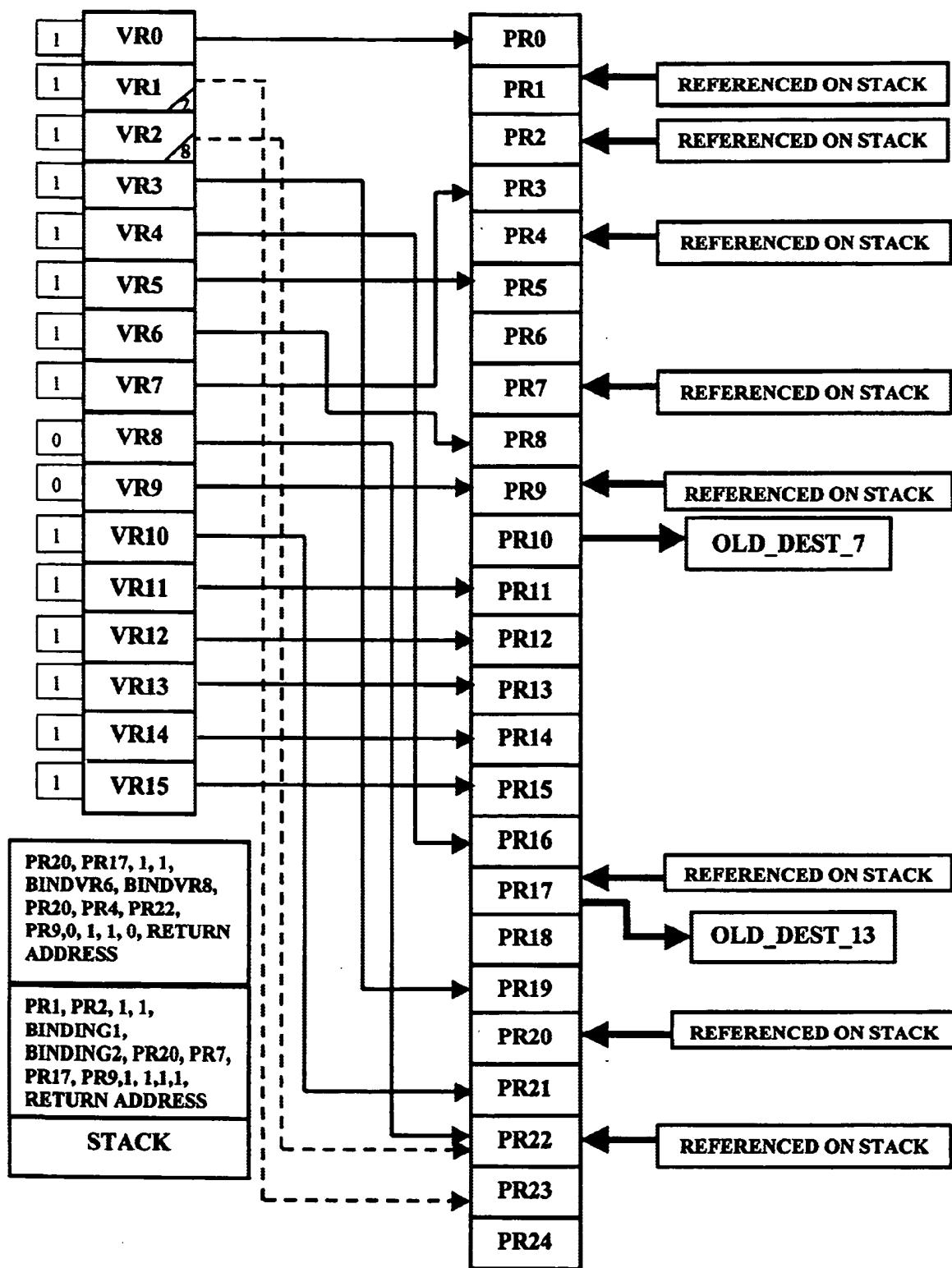
INSTR. 12: ADD VR3, VR7, VR7 maps to ADD PR19, PR4, PR3
 1 → DIRTY BIT FOR VR7

FIG. 78

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	REF'D. ON STACK
2	0	1	7	-	REF'D. ON STACK
3	0	0	-	7	WAITING FOR INSTRUCTION 12 TO EXECUTE
4	0	0	-	-	WAIT FOR INS. 9 TO EXECUTE, REF. SAVED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	-	REF'D. ON STACK
8	0	0	-	6	WAITING FOR INSTRUCTION 11 TO EXECUTE
9	0	1	21	9	REF'D. ON STACK
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-,1	INS. 2 EXECUTED, REF'D. ON STACK
18	0	1	6	-	WAITING FOR INSTRUCTION 4 TO RETIRE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	REF'D. ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8,2	WAIT FOR INS. 8 TO EXEC., REF'D. ON STACK
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

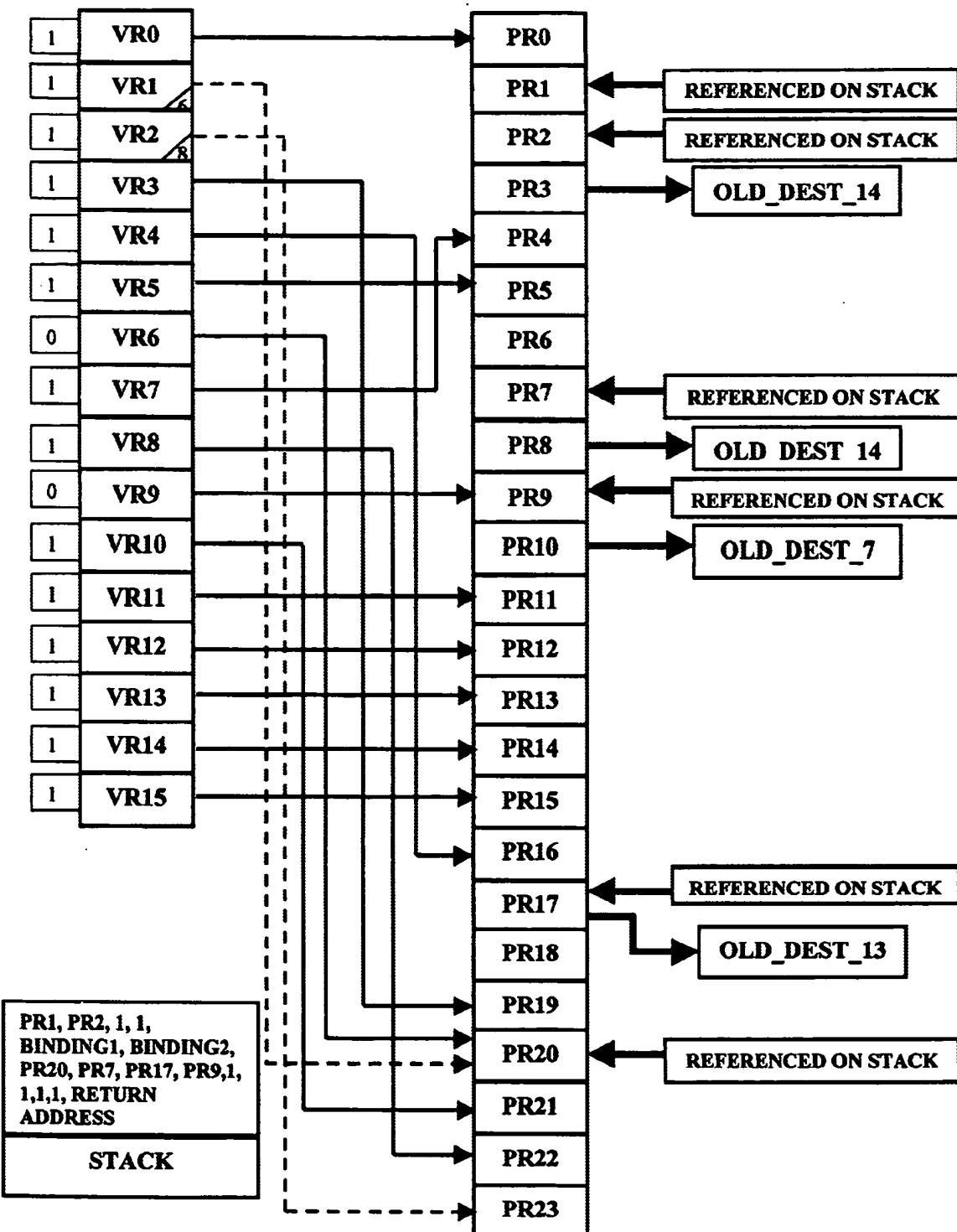
**CLOCK 7: DECODE STAGE
INSTRUCTIONS 11 & 12 PHYSICAL REGISTER STATE**

FIG. 79



INSTR. 13: MUL VR6, VR7, VR1 maps to MUL PR8, PR3, PR23
 $PR17 \rightarrow OLD_DEST_13$

FIG. 80



INSTR. 14: RET maps to
9'S DIRTY BITS,

PR20 & PR17 → VR1&2, 11 → DIRTY BITS FOR VR1&2, BINDINGS

6 AND 8 → BINDINGS FOR VR1 AND VR2, RETURN FROM SUBR. B; OLD VABR1's PR23 →
VR2 & OLD VABR1's DIRTY BIT → VR2's DIRTY BIT, OLD VABR2's PR22 → VR8 & OLD
VABR2's DIRTY BIT → VR8's DIRTY BIT, PR3 & PR8 → OLD_DEST_14

FIG. 81

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	REF'D. ON STACK
2	0	1	7	-	REF'D. ON STACK
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	0	-	7	WAIT FOR INS. 9 EXEC.
5	0	1	13	5	EXAMPLE INITIALIZATION
6	1	-	-	-	INSTRUCTION 5 RETIRED, UNALLOCATED
7	0	1	17	-	REF'D. ON STACK
8	0	0	-	-	WAIT FOR INS. 11 TO EXEC. & 14 TO RETIRE
9	0	1	21	9	REF'D. ON STACK
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INS. 2 EXEC, WAIT FOR INS. 13 TO RETIRE
18	1	-	-	-	INSTRUCTION 4 RETIRED, UNALLOCATED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	6, 1	VR6 REF. RESTORED, REF'D. ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	0	0	-	2	WAITING FOR INSTRUCTION 13 TO EXECUTE
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 8: DECODE STAGE
INSTRUCTIONS 13 & 14 PHYSICAL REGISTER STATE**

FIG. 82

TOP SECRET - NSA/CSS

80/90

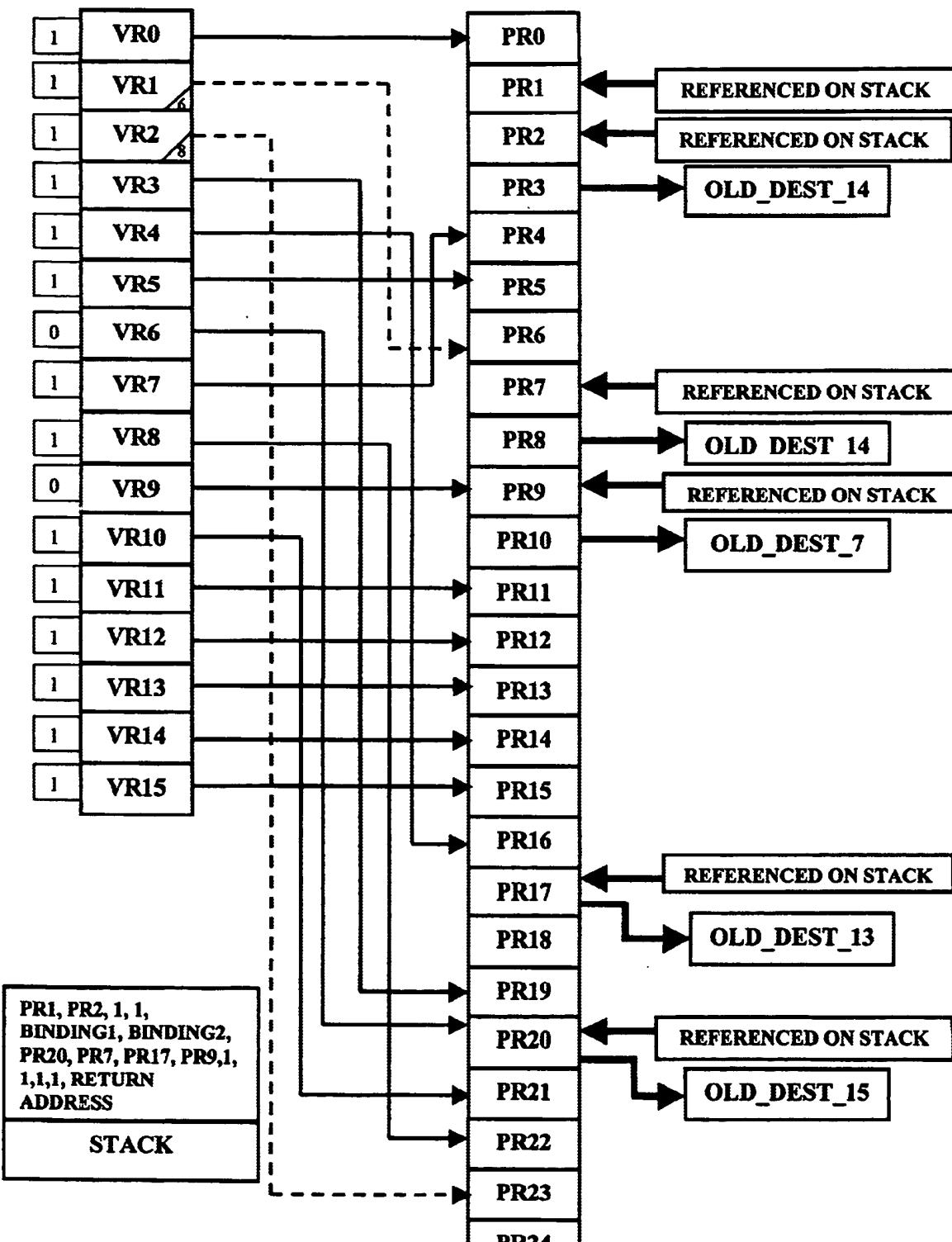
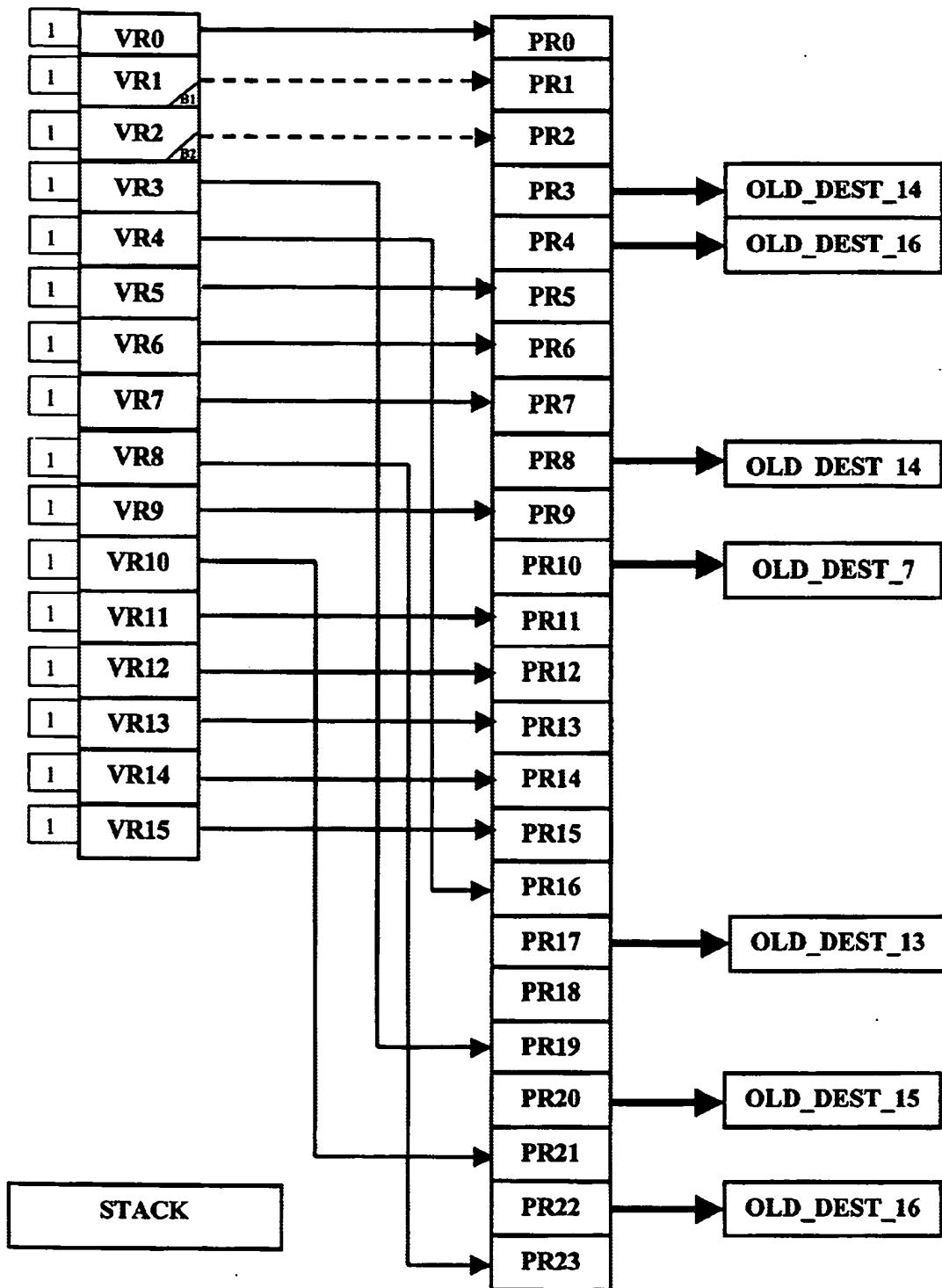


FIG. 83



INSTR. 16: RET maps to
1111 → VR6-9'S DIRTY BITS,

POP PR20, PR7, PR17, PR9 → VR6-9,

PR1 & PR2 → VR1&2, 11 → DIRTY BITS FOR VR1&2, BINDINGS

B1 AND B2 → BINDINGS FOR VR1 AND VR2, RETURN FROM SUBR. A;

OLD VABR1's PR6 → VR6, OLD VABR2's PR23 → VR8,

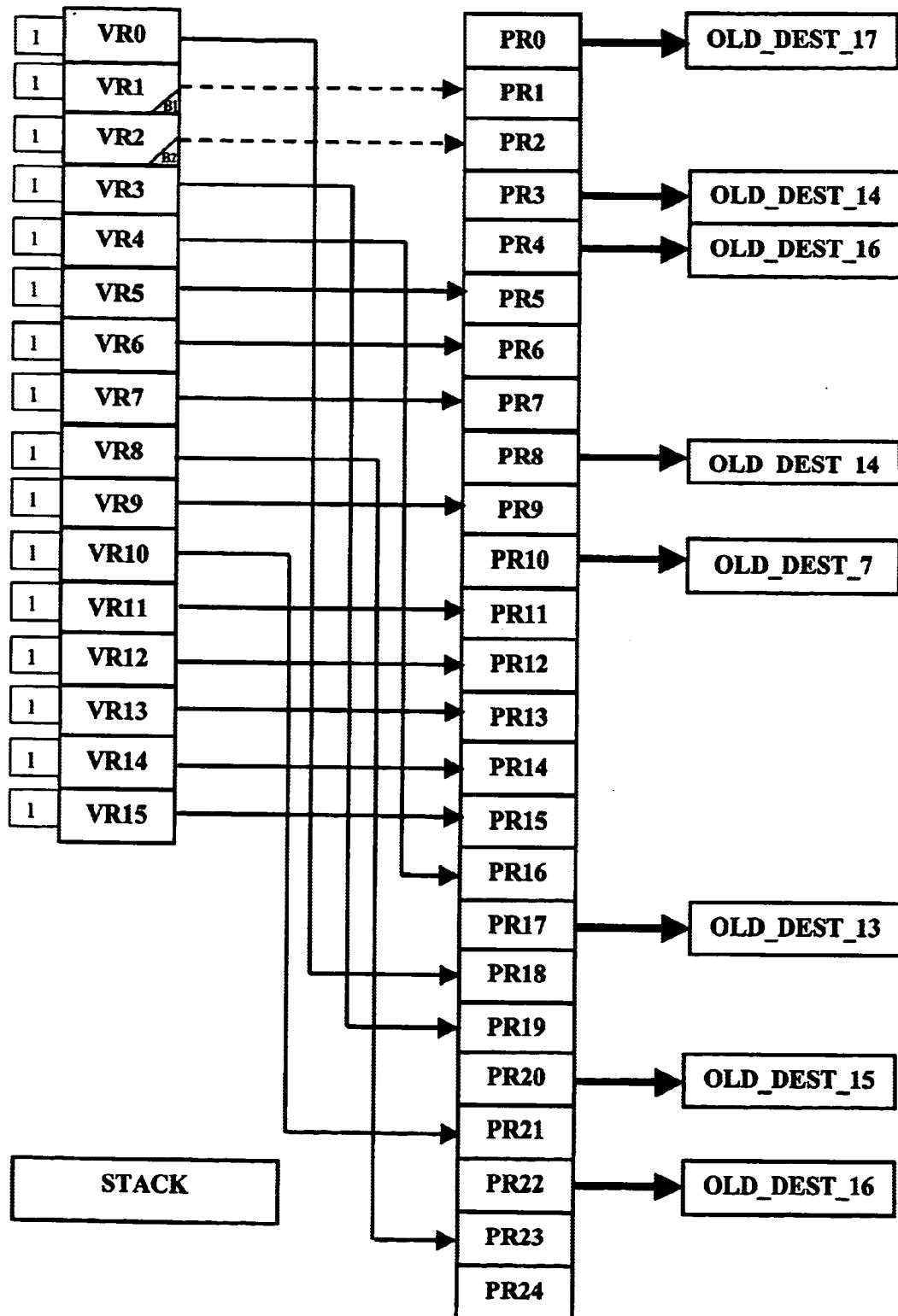
OLD VABR1&2 DIRTY BITS → DIRTY BITS FOR VR6 & 8, PR4 & PR22 → OLD_DEST_16

FIG. 84

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	0	-	-	WAIT FOR INS. 9 EXEC., INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	6	WAITING FOR INSTRUCTION 15 TO EXECUTE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	0	-	-	WAIT FOR INS. 11 TO EXEC. & 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	1	-	-	-	INSTRUCTION 4 RETIRED, UNALLOCATED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

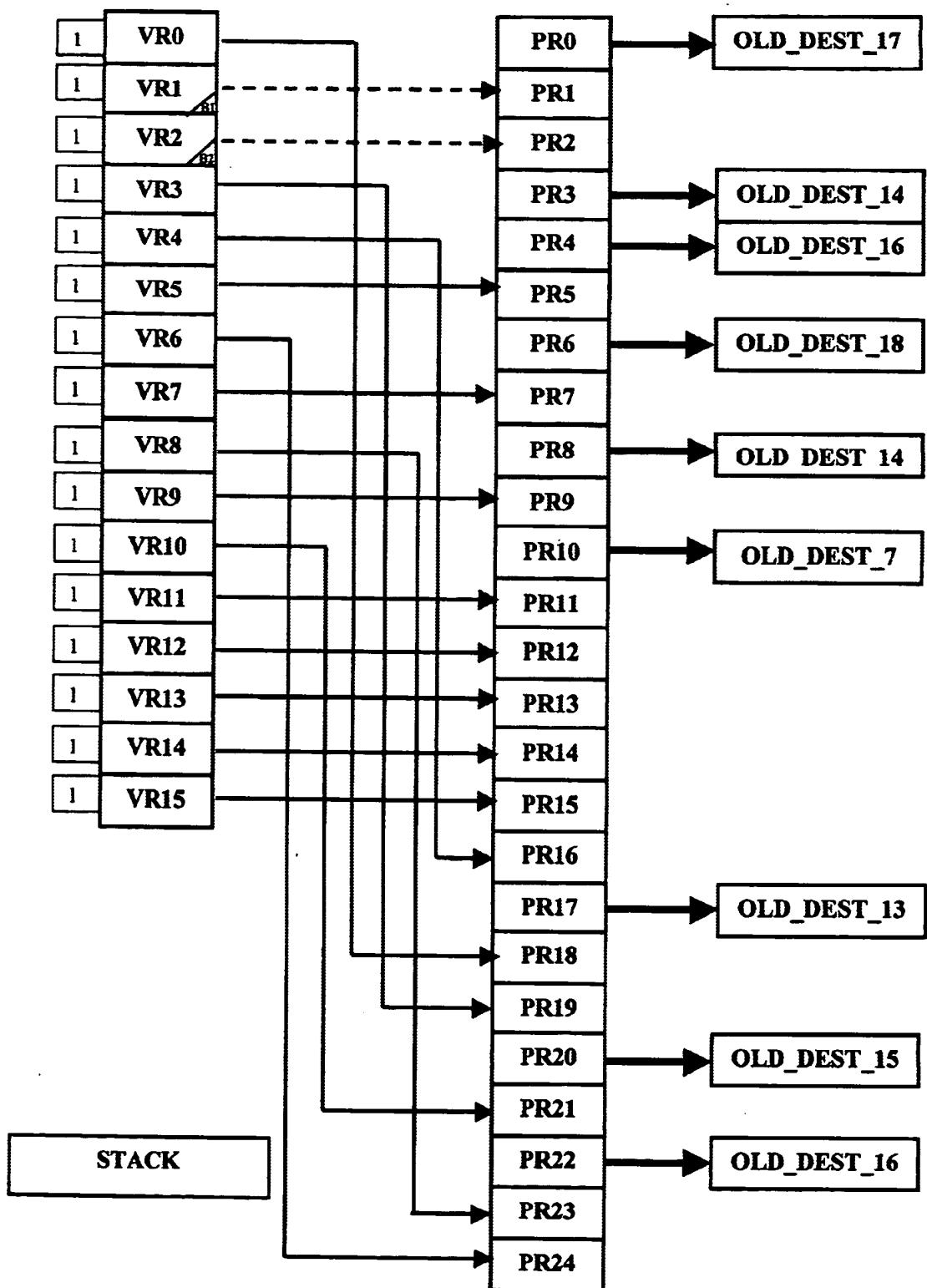
**CLOCK 9: DECODE STAGE
INSTRUCTIONS 15 & 16 PHYSICAL REGISTER STATE**

FIG. 85



INSTR. 17: ADD VR8, VR0, VR0 maps to ADD PR23, PR0, PR18
 $PR0 \rightarrow OLD_DEST_{17}$

FIG. 86



INSTR. 18: ADD VR8, VR6, VR6 maps to ADD PR23, PR6, PR24
 $PR6 \rightarrow OLD_DEST_{18}$

FIG. 87

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	-	WAIT FOR INS. 15 TO EXEC. & 18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED, UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	WAITING FOR INS. 13 TO RETIRE
18	0	0	-	0	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	0	0	-	6	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 10: DECODE STAGE
INSTRUCTIONS 17 & 18 PHYSICAL REGISTER STATE**

FIG. 88

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	-	WAIT FOR INS. 15 TO EXEC. & 18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED, UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	0	0	-	0	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	6	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	0	0	-	6	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 11: DECODE STAGE
NO CHANGE IN PHYSICAL REGISTER STATE**

FIG. 89

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	792	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	790	-	WAIT FOR INS. 18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	0	0	-	0	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	0	0	-	6	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 12: DECODE STAGE
PHYSICAL REGISTER STATE**

FIG. 90

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	792	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	790	-	WAIT FOR INS. 18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	0	1	25347	0	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	0	1	26134	6	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 13: DECODE STAGE
PHYSICAL REGISTER STATE**

FIG. 91

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	792	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	790	-	WAIT FOR INS. 18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	0	1	25347	0	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	1	25344	8	INSTRUCTION 13 EXECUTED
24	0	1	26134	6	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 14: DECODE STAGE
PHYSICAL REGISTER STATE**

FIG. 92

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	1	-	-	-	INS. 17 RETIRED, UNALLOCATED
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	1	-	-	-	INSTRUCTION 14 RETIRED, UNALLOCATED
4	1	-	-	-	INSTRUCTION 16 RETIRED, UNALLOCATED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	1	-	-	-	INSTRUCTION 18 RETIRED, UNALLOCATED
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	1	-	-	-	INSTRUCTION. 14 RETIRED, UNALLOCATED
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED, UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	1	-	-	-	INS. 13 RETIRED, UNALLOCATED
18	0	1	25347	0	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	1	-	-	-	INS. 15 RETIRED, UNALLOCATED
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	1	-	-	-	INSTRUCTION 16 RETIRED, UNALLOCATED
23	0	1	25344	8	INSTRUCTION 13 EXECUTED
24	0	1	26134	6	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

**CLOCK 15: DECODE STAGE
PHYSICAL REGISTER STATE**

FIG. 93

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